4 GUAM & ADJACENT REEFS

4.1 Introduction

The island of Guam, or Guåhan in the native Chamorro language, is centered at 13°28′ N, 144°47′ E and is the only major island in the United States territory of Guam. With a total area of 544.34 km², Guam is the largest island in the Mariana Archipelago. The highest point on Guam is Mount Lamlam at 406 m. The major population centers are in a central section of this island near Apra Harbor, Hagåtña, and Tumon Bay as well as in a northern section in a stretch of development between Tumon Bay and Andersen Air Force Base (Fig. 4.1.4b). Tumon Bay is the main tourist center with numerous hotels, the Guam International Airport, and other tourist facilities in the immediate area. Apra Harbor on the central west coast of Guam is one of the largest harbors in the western Pacific and supports both military and civilian commerce. The geology of Guam is unique in the Mariana Archipelago because the northern half is flat, uplifted limestone but the southern half is of Eocene volcanic origin and highly susceptible to erosion. Three shallow banks, all popular fishing areas, are located offshore: Santa Rosa Reef lies 46 km southwest of Guam and has a least depth of 8 m, Galvez Bank lies 22 km southwest of Guam and has a least depth of 25 m, and 11-mile Reef lies 17 km west of the southern point of Guam and has a least depth of 20 m.

4.1.1 History and Demographics

A brief summary of Guam's history and political structure is presented here. The history of the Mariana Archipelago and the political structure of Guam and the Commonwealth of the Northern Mariana Islands (CNMI) are discussed in Chapter 1: "Introduction."

The history of Guam runs parallel to that of many other islands of the Mariana Archipelago until the late 1800s. A native Chamorro population was established as early as 3500 years ago (Rogers 1995). Ferdinand Magellan established contact with Guam in 1521, and Spain ruled between 1565 and 1898 (Rogers 1995). Guam was ceded to the United States in 1898 after the Spanish American War and purchased in 1899 for US$20 million. Guam was used as a refueling and communications station and was on the Pan American Airways *China Clipper* route between 1935 and World War II (WWII) (Rogers 1995). For the first 4 decades of U.S. control, from 1898 to WWII, Guam was administered by the U.S. Navy with a naval officer serving as governor.

Japanese forces invaded Guam in 1941 and held it until 1944, when American forces reclaimed the island. Thereafter, this island was used as the command post for the U.S. western Pacific until 1945, and U.S. Navy control was re-established in 1946 (Rogers 1995). Administration of Guam was transferred in 1950 from the Department of Defense to the Department of the Interior, Office of Insular Affairs. Guam became an organized, unincorporated territory of the United States when the U.S. Congress passed the *Organic Act of Guam* in 1950. The *Organic Act* gave the people of Guam U.S. citizenship, a status for which they had petitioned since 1902 (Rogers 1995). As an unincorporated territory Guam belongs to, but is not a part of, the United States, and no guarantee of eventual statehood is implied. The United States appointed the governor of Guam until 1968, when the *Organic Act* was amended to authorize the holding of an election; the first election for governor was held in 1970. Federal legislation awarded Guam a delegate in the U.S. House of Representatives in 1972. This delegate can participate and vote in House committees and has limited rights for voting on floor amendments. The *Organic Act* also transformed the existing Guam Congress into a lawmaking body, but Guam's legislation is still subject to the will of the U.S. Congress (Howe et al. 1994). Under the U.S. Constitution, residents of unincorporated territories, such as Guam, do not vote in elections for U.S. president and vice president; however, they may vote in presidential primary elections. The governor and lieutenant governor of Guam are chosen jointly with a single vote applicable to both offices for 4-year terms (Governor… 2006).

Guam had an estimated human population of 159,358 persons in 2010, a 3% increase from the island's population in 2000 and a 50% jump from its population in 1980 (Fig. 4.1.1a; U.S. Bureau of the Census 1982, 2002, 2011b). A major population increase is expected in the next decade, since the United States plans to relocate between 4700 and 8000 Marines with accompanying dependents and support personnel to Guam from Okinawa, Japan (Parrish 2012; Hart 2012). The military-related population on Guam, which in 2008 included ~ 14,000 service members stationed on this island, could grow by an

estimated 24,713 service members, military dependents, and support staff over the next decade (U.S. Department of the Navy 2010; Weaver 2008). An increase in civilian population also is anticipated as additional construction and service jobs become available in the private sector.

Figure 4.1.1a. Population growth (U.S. Bureau of the Census 1982, 1992, 2002, 2011b; Secretariat of the Pacific Community 2011; U.S. Department of Defense) and visitor count (A Cid, Guam Visitors Bureau, pers. comm.) trends on Guam during the period of 1967–2015.
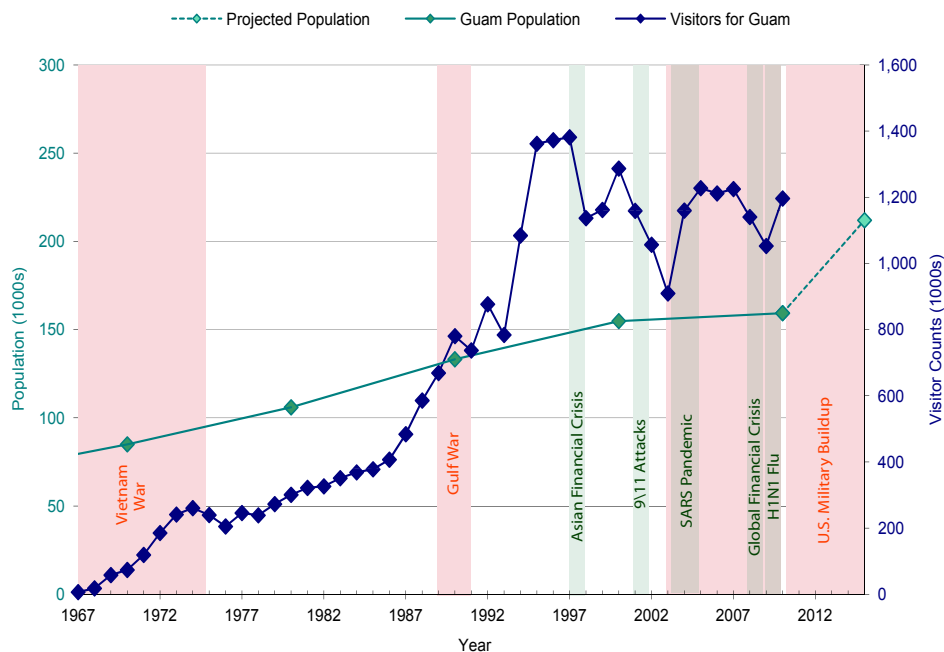
4.1.2   Land Use

Current land use on Guam is predominantly characterized as urban, forest, and shrub (Fig. 4.1.2a). This island's northern limestone plateau was once heavily forested, but significant changes to that vegetation have taken place during and after WWII as a result of military activities and urbanization (Minton 2005). This area is now the major population center with some scattered areas of remaining forest. U.S military installations on Guam cover 160 km², ~ 29% of this island's total land area. The largest installations are Naval Base Guam, most of which is located on Orote Peninsula on the central west side of Guam, and Andersen Air Force Base in the northeast corner of Guam. The southern volcanic area is largely range-land and savannah with some lightly populated areas on the young limestone terrain along the east coast. This mountainous, southern area has numerous barren areas created by wildfires (Fig. 4.1.2a) that occur at an average of more than 700 per year and are reportedly set by poachers and hunters, and these barren areas contribute to erosion problems in the steep volcanic terrain (Burdick et al. 2008).

Guam has 5 marine protected areas (MPAs) including; Piti Bomb Holes Marine Preserve, Sasa Bay Marine Preserve, Tumon Bay Marine Preserve, Pati Point Marine Preserve, and Achang Reef Flat Marine Preserve. Established in 1997 by the government of Guam, these MPAs cover more than 10% of Guam's coastline and a total area of ~ 36 km². In addition, the U.S. Fish and Wildlife Service has established the Guam National Wildlife Refuge at Ritidian Point, and the Navy has established 2 ecological reserves at Orote Point and Haputo (Burdick et al. 2008).
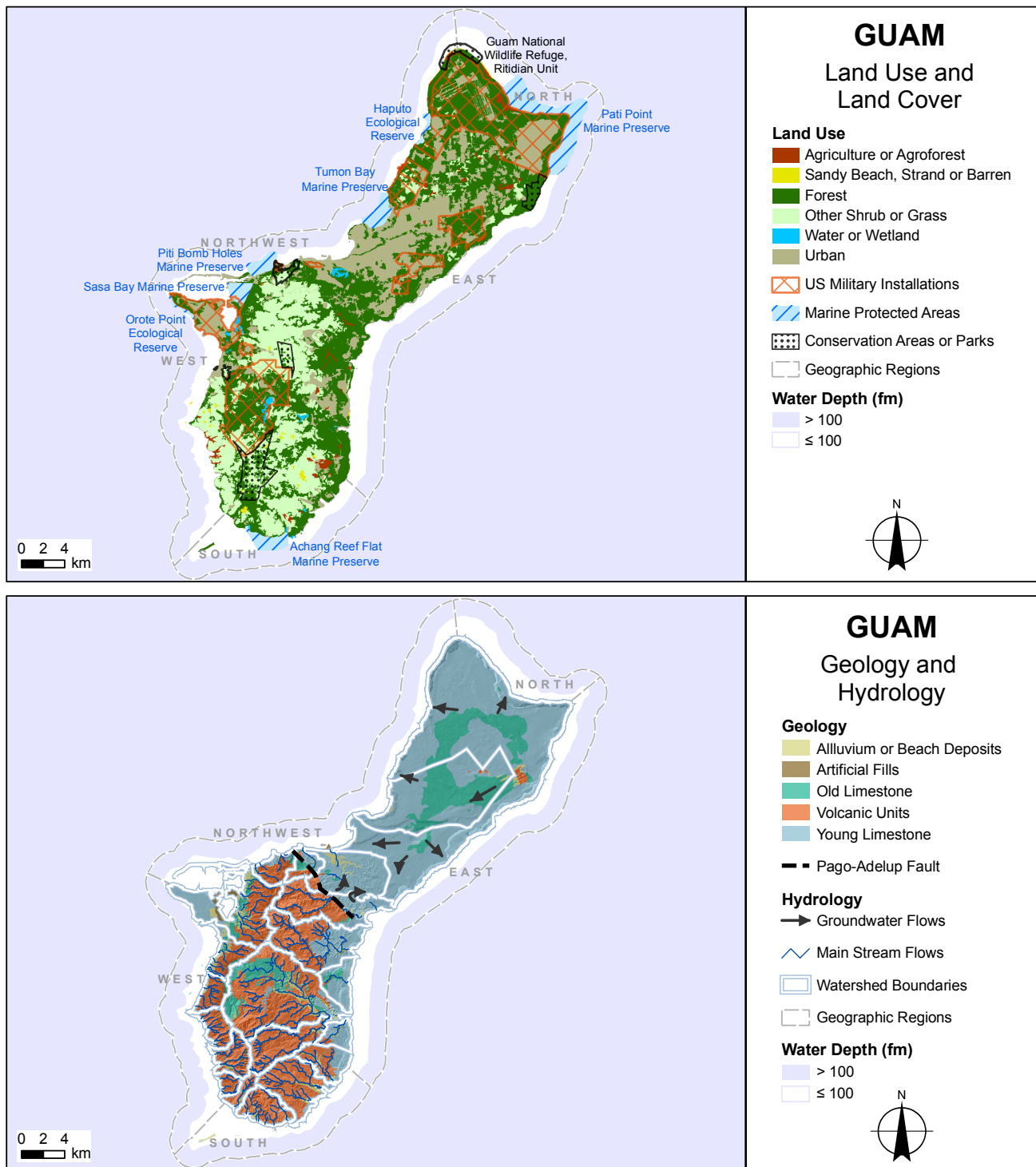
Figure 4.1.2a. Land use (U.S. Department of Agriculture Forest Service 2006c), military installations (U.S. Bureau of the Census 2008), conservation areas and parks (Burdick et al. 2008), and marine protected areas (MPAs; NOAA Marine Protected Areas Center 2008) on Guam are represented over a vegetation cover map (*top*; Liu and Fischer 2006). Geology (Water and Environmental Research Institute of the Western Pacific and Island Research and Education Initiative 2009; Tracey et al. 1964; Gingerich 2003), watersheds (Guam Environmental Protection Agency 2008), main stream flows (U.S. Geological Survey 2005c), and groundwater flows (Gingerich 2003) on Guam (*bottom*).

4.1.3 Geography

Guam is the southernmost island of the Mariana Archipelago, one of a series of volcanic arcs that extend north to Japan. Guam lies in the southern, inactive Mariana Arc, rather than in the volcanically active northern Mariana Arc. The oldest

geologic formations on Guam date as far back as the mid- to late-Eocene epoch or 33–48 million years ago (Hawkins 2003). This island is tectonically active and has undergone repeated uplift and subsidence related to subduction of the Pacific Plate and associated seamounts into the Mariana Trench, ~ 100 km to the east (Riegl et al. 2008).

The island of Guam has a distinctive north–south divide, which is highlighted by both the geologic map (Fig. 4.1.2a) and the combined onshore-offshore slope map (Fig. 4.1.3a). The southern part of this island is dominated by volcanic features, while the northern part's flat, uplifted, coral limestone is similar to the geology of Rota, Tinian, Aguijan, and Saipan. Formerly densely forested but now mixed urban and forest land, the northern limestone plateau on Guam is surrounded by cliffs. The plateau is separated from the southern half of Guam by the major northwest–southeast trending Pago-Adelup fault (Taboroši et al. 2005). Southern Guam is more mountainous than the northern part, and its geology is dominated by basalt, relic volcanoes that have erupted through uplifted coral limestone. This volcanic region's flanks have numerous bays, canyons, and valleys, and much of this area is covered by grasslands (Kingston 2004).

Because of its geology, Guam's water supply comes from 3 distinct sources. The flat, porous, carbonate plateau in the north has no surface rivers or streams and, thus, no true watersheds. Virtually all rainfall in northern Guam infiltrates the porous limestone and is stored as groundwater (Fig. 4.1.2a), which flows into an underlying Ghyben-Herzberg lens of water that is accessed via wells (Gingerich 2003). Springs in this island's central area, near the Pago-Adelup fault, supply ~ 3% of the water on Guam. The southern volcanic area, which has more than 40 streams and stream-cut valleys and 14 major watersheds, is very steep on the west side (Fig. 4.3.1g in Section 4.3: "Benthic Habitat Mapping and Characterization"). The volcanic laterite soils in the barren areas on Guam are subject to severe erosion (Water and Environmental Research Institute of the Western Pacific 2009); laterite soil is a red, hard, or gravel-like soil or subsoil formed in the tropics that has been leached of soluble minerals leaving insoluble iron and aluminum. A small volume of water penetrates the volcanic rock to form a subsurface lens in the volcanic areas, and the water supply in this area is primarily drawn from the Ugam River and the Fena Reservoir. The primary water suppliers are the Guam Waterworks Authority, the U.S. Navy, and the U.S. Air Force. (Kingston 2004).

Figure 4.1.3a. Combined slope map using the digital elevation model and multibeam bathymetric data for Guam.
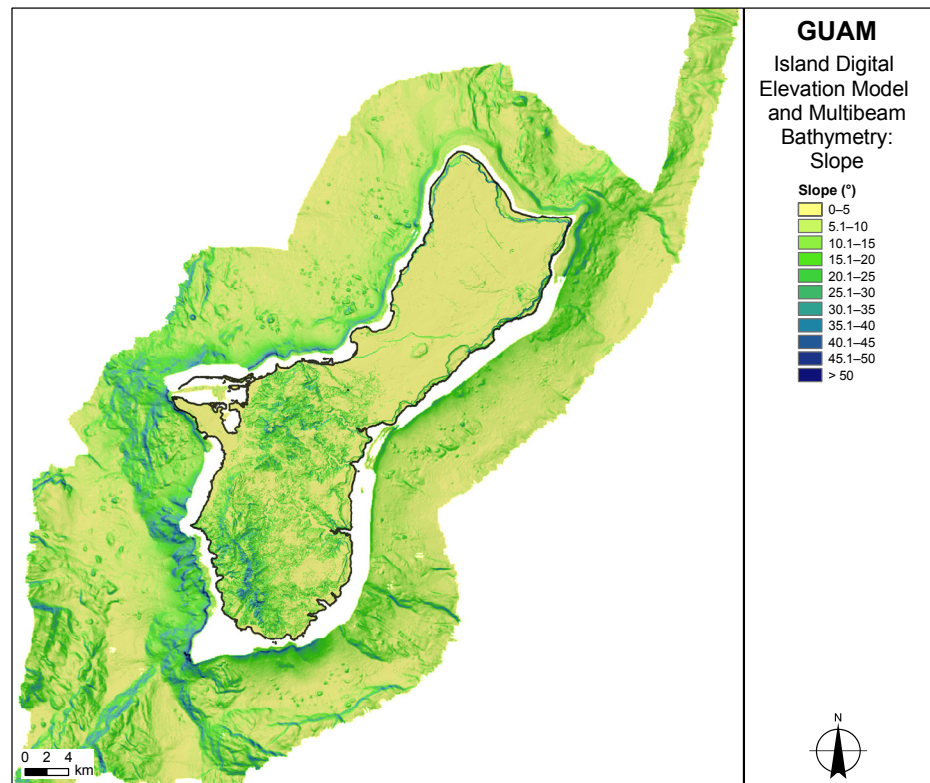
4.1.4   Economy

The 2 most important sectors of the Guam economy are tourism and U.S. government spending (including for military installations). Other sources of income include local government, local business, and fishing. A recent estimate of total

economic activity in Guam for 2000 was \$3.4 billion (Allen and Bartram 2008). In 2008, the services sector of Guam's economy employed 16,605 people, accounting for 26.8% of the workforce on Guam, and the sectors with the next-greatest proportion of employment were retail trade, the government of Guam, and construction with 19.5%, 18.9%, and 10.6% (Guam Department of Labor 2008). The government of Guam was the single largest employer (Allen and Bartram 2008). In the 1960s, the federal government, including the military, accounted for 75% of Guam's economy; this percentage decreased to 30% in 2003 (Guam Visitors Bureau 2004).

Tourism provides the majority of Guam's nongovernmental income with ~ 1.2 million tourists visiting each year. The tourism industry has had many ups and downs (Fig. 4.1.1a) over the past 20 years, with a peak of 1.4 million tourists visiting in 1995 and 1997 and numerous lows associated with a weak Asian economy, the events of September 11, 2001, typhoons, and recent worldwide economic problems (Allen and Bartram 2008).
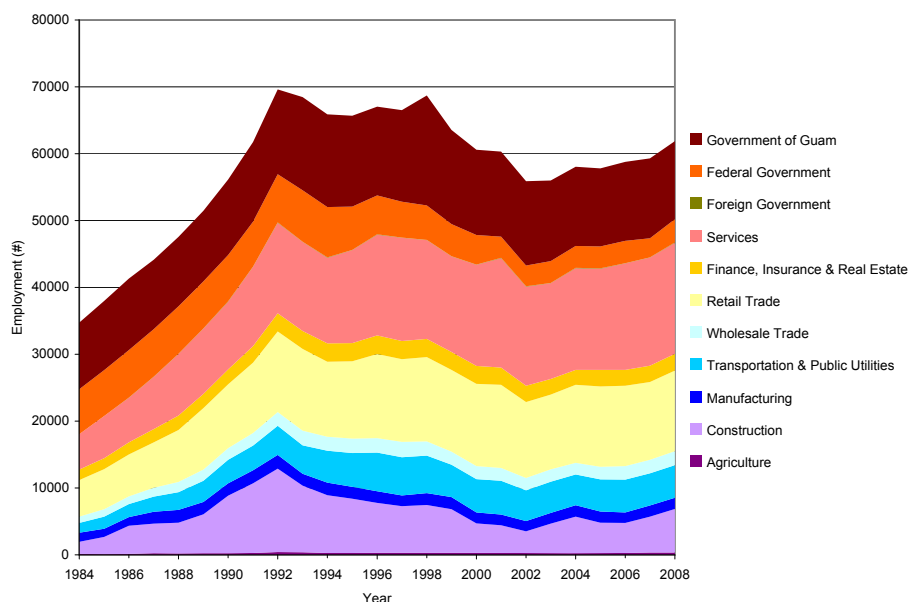

Figure 4.1.4a. Employment by sector on Guam during the period of 1984–2008 (Guam Department of Labor 2008).

Japan is the source of 80% of tourists to Guam, who stay an average of only 3 nights (Guam Economic Development Authority 2009b). Korea, Taiwan, Hong Kong, the Philippines, and the United States are the other main sources of tourists and the number of tourists from Russia and China has increased in recent years (Guam Visistors Bureau). Since the region's immigration laws were federalized in May 2008, officials from both Guam and the CNMI have been seeking visa waivers for Russian and Chinese visitors to bolster tourism and their economies (Casas 2009). The area near Tumon Bay, which was designated as a marine preserve in 1997, is the primary area for tourism with more than 20 hotels and other facilities. Many tourism activities, including golfing, scuba diving, beach going, and deep-sea fishing, are dependent upon and impact Guam's natural resources (Fig. 4.1.4b).

Guam has been the location of strategic U.S. military posts in the Pacific for over a century. With the withdrawal of troops from the Philippines in the 1980s and the planned move of troops from Okinawa in the next decade, Guam has become even more critical as a location for strategic U.S. military operations (Pessin 2006). The annual military spending in Guam ranged from \$883 million to \$1.1 billion from 1993 to 2000 (Allen and Bartram 2008). A large increase in construction activities is planned as a result of this military buildup including construction of an aircraft carrier pier, turning basin, expansion of the commercial port, housing construction, and expansion of infrastructure. It has been estimated that \$15 billion would be spent over a period of 10 years for military activities in Guam (Laney 2008).

While commercial fishing has not been a major contributor to Guam's economy, the territory has been a major regional fish transshipment center and resupply base of domestic and foreign tuna fishing fleets; however, Guam's role as a transshipment center has declined in the past several years (Allen and Bartram 2008). Local fishing in Guam is important because it contributes to the subsistence needs of the indigenous Chamorro population and preserves culture and identity. Guam's coral reef fisheries currently target a large number of reef fishes and invertebrates. Harbors and marinas, which serve as primary fishing access points, are located in the south, west, and northwest regions of Guam (Fig. 4.1.4b). Sport fishing ves-
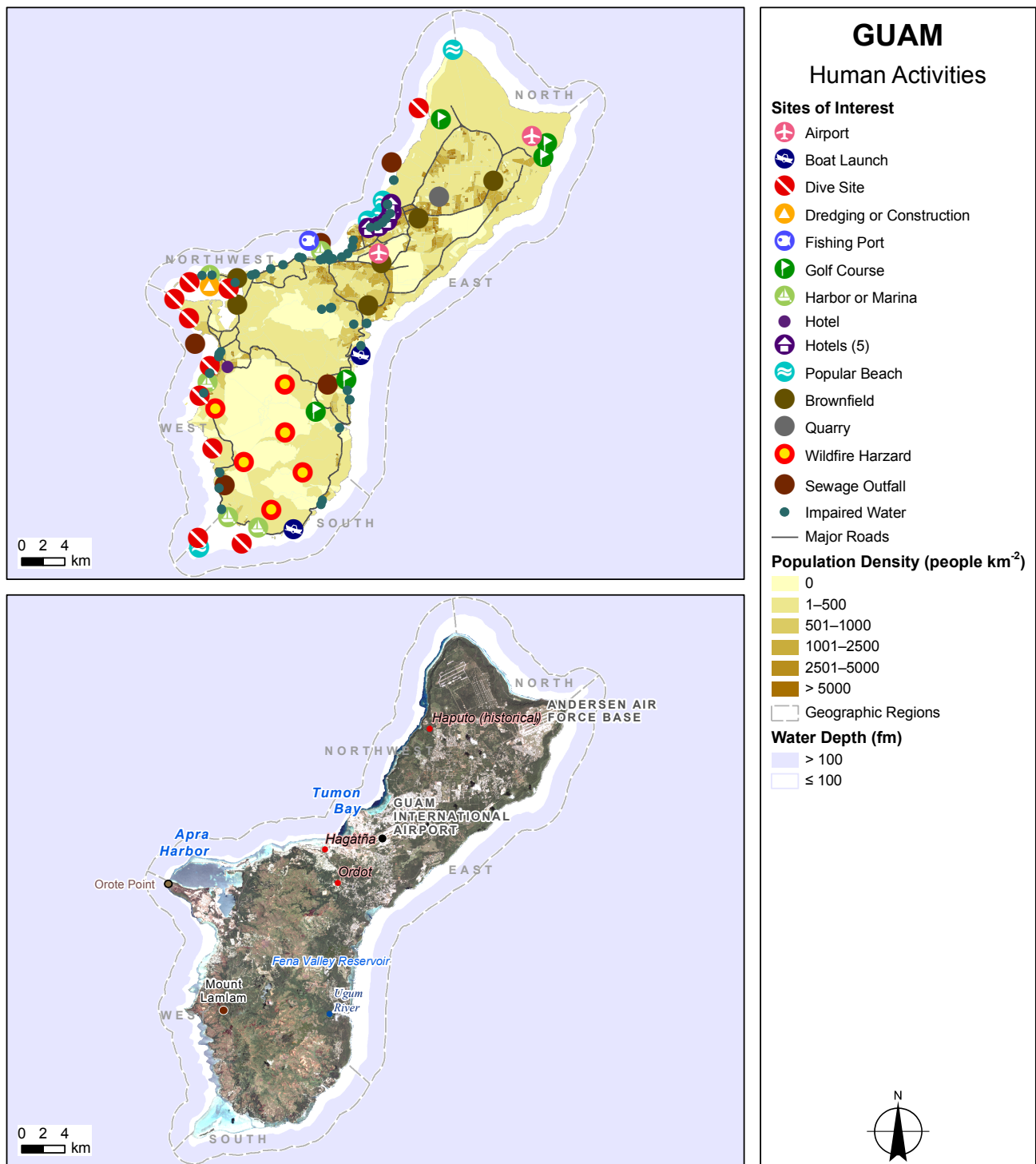
Figure 4.1.4b. Major locations of human activities (*top*) on Guam that have the potential to affect the marine environment (Burdick et al. 2008; Franko Maps Ltd.; Guam Economic Development Authority 2009b; Placenames.com; U.S. Geological Survey 2005d; AL Guerrero, Guam Environmental Protection Agency, pers. comm.) are represented over a population-density map (U.S. Bureau of the Census 2002, 2008). Satellite imagery of Guam (*bottom*, includes material © 2006 DigitalGlobe Inc. All rights reserved), labeled with places of interest (U.S. Geological Survey).

sels and the Guam Fishermen's Cooperative Association, an active commercial fishing cooperative, are located in Hagåtña Harbor. Two boat launching ramps on windward shores in the east and south regions are seldom used, according to local residents (V Brown, JIMAR, pers. comm.). In the mid-1980s, a rapid shift from subsistence to commercial fishing activities occurred in response to increased tourism and development (Richmond et al. 2008). Four studies discussed in Burdick et al. (2008) show that the catch per unit effort and harvest have declined over the past 20 years for shore-based fisheries.

To combat the decline of fish stocks, the government of Guam created a system of marine preserves designed to increase fish stocks through limited-take or no-take zones. Subsequently, fish stocks in these preserves have increased (Burdick et al. 2008). Legislation (Public Law 29-127) that passed in late 2008 could open some of these no-take marine preserves to fishing by indigenous people (Naylor-Gesick 2008).

The Division of Aquatic and Wildlife Resources (DAWR) of the Guam Department of Agriculture, with technical assistance from the Western Pacific Fisheries Information Network (WPacFIN) of the NOAA Pacific Islands Fisheries Science Center, has been collecting nearshore fisheries-dependent creel survey data in Guam continuously since 1982, allowing for exploration of temporal trends in the local fisheries of this territory. According to this survey data (DAWR), fishermen around Guam who target nearshore species typically use one of the following methods: spearing (scuba or freediving), nets, trolling, or bottom fishing. These fishermen can be based on shore or in a boat. Trolling almost exclusively captures tunas and mackerels (Scombridae), which together account for 99% of landed catch by weight from trolling. Bottom fishing captures mostly deep species of emperors (Lethrinidae), snappers (Lutjanidae), and jacks (Carangidae), which account for a combined 70% of landed catch by weight from bottom fishing and are not currently surveyed as part of MARAMP. Spearing and netting data are reported in more detail here, because these methods capture the nearshore species typically found on coral reefs. Around Guam, boat-based spearfishermen mostly capture surgeonfishes (Acanthuridae) and parrotfishes (Scaridae; Fig. 4.1.4c), which together account for 66% of landed catch by weight from boat-based spearfishing—a proportion that has been remarkably constant for nearly 30 years. Interestingly, parrotfishes have decreased from 40% of the landed catch by weight from boat-based spearfishermen in the 1980s to 20% in recent years (Fig. 4.1.4d). Conversely, surgeonfish catch has increased from 20% to 40% of landed catch by weight. Other important families found in spearfishing landings are groupers (Serranidae, 14%), snappers (9%), and jacks (5%). Gillnet landings are composed mostly of goatfishes (Mullidae, 48%), followed by surgeonfishes (17%) and rabbitfishes (Siganidae, 10%).
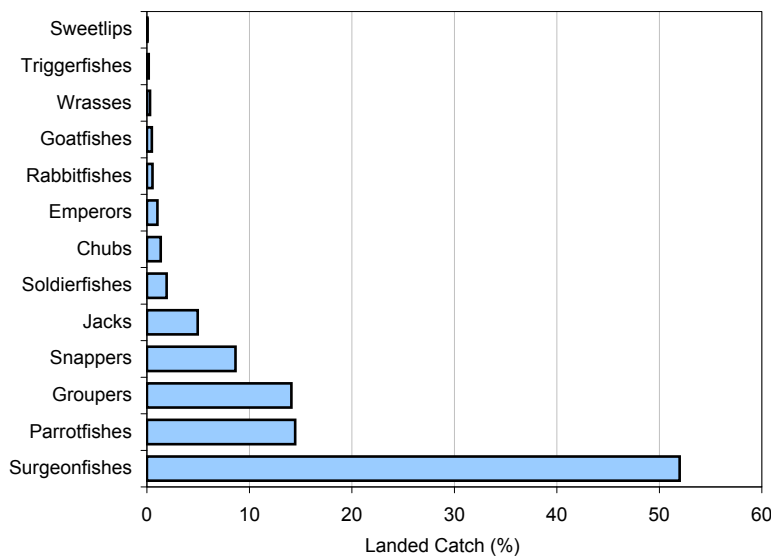
Figure 4.1.4c. Family composition of the landed catch of spearfishermen, by weight as a proportion of total catch, around Guam in 2008 (DAWR). Data were collected from boat-based creel surveys conducted by the Guam DAWR and extrapolated to estimate total catch with assistance from the WPacFIN.
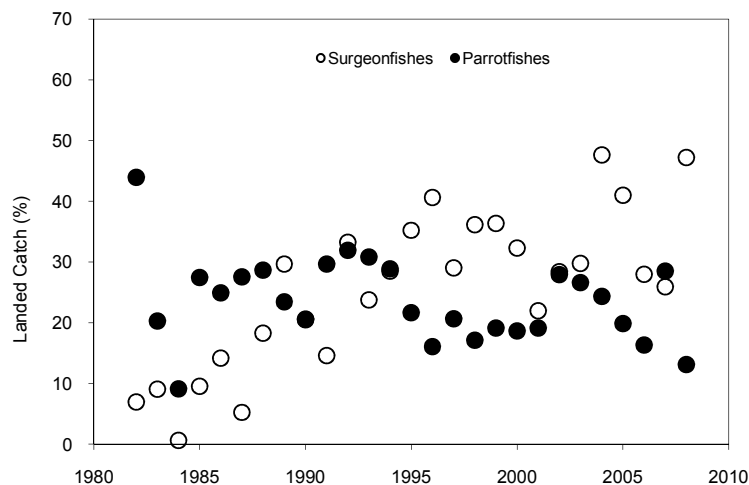
Figure 4.1.4d. Estimated landed catch (%) of parrotfishes and surgeonfishes as a proportion of total landed catch by boat-based spearfishing. These catch estimates come from an expanded data set based on creel surveys conducted by the Guam DAWR.

4.1.5 Environmental Issues on Guam

The condition of Guam's coral reefs ranges from excellent to highly degraded by human impacts (Burdick et al. 2008). Local assessment and monitoring projects on Guam, primarily in accessible areas on the west and northwest regions have been conducted intermittently since the 1970s (Richmond et al. 2008). The Pacific RAMP began conducting biennial surveys around the coasts of Guam in 2003.

Although climate change—including potential increases in coral bleaching and resultant coral disease, ocean acidification, and increased storm frequency—has not been documented to have caused problems in Guam (Burdick et al. 2008), these global issues are considered by many to be the overall greatest threats to coral reefs in the coming decades (Hoegh-Guldberg et al. 2007). In addition, rises in sea level could impact water supplies, particularly in northern Guam where the Ghyben-Herzberg lens, a body of rain-fed freshwater depressing and overlying a body of sea-fed saltwater, lies near sea level (Maas 2007).

The Guam Environmental Protection Agency (GEPA) has numerous programs in place that support the protection and improvement of water quality on and around Guam. The U.S. Environmental Protection Agency (EPA) approved on June 1, 2009, a list of sites where impaired or threatened waters were found in accordance with Section 303(d) of the *Clean Water Act*. In this approved list and in a water-quality monitoring and assessment report, titled "2008 Integrated Report," the GEPA identifies impaired or threatened waters at 43 sites around Guam, including bays, coral reefs, sea grass beds, and estuarine systems (for the locations of these sites, see Fig. 4.10b in Section 4.10: "Ecosystem Integration;" Guam Environmental Protection Agency [GEPA] 2008).

Impaired waters are identified when a site does not meet general and numeric criteria. According to general criteria, waters must meet aesthetic qualifications, be capable of supporting "desirable aquatic life," and be free from substances or conditions attributable to discharges (domestic, commercial, or industrial) agriculture, construction, land-use practices, or other human activities. Numeric requirements set thresholds or ranges for the levels of concentrations of bacteria and nutrients, pH, dissolved oxygen, salinity, suspended solids, turbidity, temperature change, petroleum products, and toxic substances (GEPA 2001).

Of the 15.08 km of shoreline monitored around Guam, 0.74 km attained Guam water-quality standards (GWQS) in 2007, a drop from 1.11 km in 2006. Bacteria impaired 13.97 km of coastline in 2006 and 14.34 km in 2007. Impaired waters at recreational beaches were primarily caused by *Enterococcus* bacteria, a pathogen indicator. Still, marine waters around Guam were generally classified as "good," meaning that waters were of "sufficient quality to allow for the propagation and survival of marine organisms, particularly shellfish and other similarly harvested aquatic organisms, corals and other reef-related resources, and whole body contact recreation. Other important and intended uses include mariculture activities, aesthetic enjoyment, and related activities." (GEPA 2008)

Impacts generally have not been well documented, but numerous controversial local environmental issues on Guam (Burdick et al. 2008; Rodda and Savidge 2007) affect coral reefs, including the following issues:
- Sedimentation and runoff caused by
  - Coastal development
  - Dredging and construction in Apra Harbor
  - Severe upland erosion caused by deforestation and illegal burning by hunters and farmers, particularly on the southwest coast
- Coastal pollution caused by
  - Outfalls from sewage treatment plants near coral reefs
  - Inadequate sewage treatment facilities
  - Leakage into groundwater from septic tanks and sewage spills (nitrate, protozoa, bacteria, and viruses)
  - Storm water drainage, especially during heavy rainfall
  - Urban runoff, which can include inorganic and organic pesticides, halogenated solvents, petroleum compounds, and nitrates
  - Nutrients from farms and golf courses (pesticides and fertilizers)
  - Polychlorinated biphenyls (PCBs) from military dumps
  - Potential contamination from the 50-year-old dump, which was ordered closed in 2007, at Ordot
  - Overuse or misuse of popular scuba and snorkeling sites
  - Use of mechanical beach cleaning equipment at Tumon Bay and east Hagåtña Bay
  - Personal water craft

- Declining fish catch caused by
  - Fishing pressures
  - Fishing methods and practices
  - Habitat loss because of sedimentation, pollution, and physical damage
- Damage to coral reefs caused by frequent typhoons
  - Physical damage from large offshore waves
  - Increased influx of contaminated rainwater from the land
- Periodic outbreaks of crown-of-thorns seastars (*Acanthaster planci*)
- Damage to the environment by the brown tree snake (*Boiga irregularis*)
  - Extinction of 10 out of the 12 native forest bird species, leading to reductions in avian seed dispersal, subsequent alteration or loss of plant cover, and increased runoff

The predicted 25% increase in Guam's population (Weaver 2008) over the next decade is expected to exacerbate many of these environmental threats to terrestrial and coral reef ecosystems. Increased military and commercial construction projects, along with associated environmental assessments and planning, are already overburdening limited environmental government agencies and their available resources (Burdick et al. 2008). Construction of infrastructure—including expansion and improvement of public landfills, water supply, and sewage treatment facilities—is necessary to support a large influx of military personnel and their dependents over the next decade, and there are concerns that these activities could potentially increase coastal runoff and pollution (Burdick et al. 2008). During this time of rapid growth and development, both sound ecosystem-based management and frequent, continued monitoring become even more critical to the conservation and preservation of coral reef ecosystems around Guam.

4.2   Survey Effort

Extensive biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing coral reef ecosystems around the island of Guam since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 5 geographic regions around Guam are delineated in Figure 4.2a; wave exposure and breaks in survey locations were considered when defining these geo-
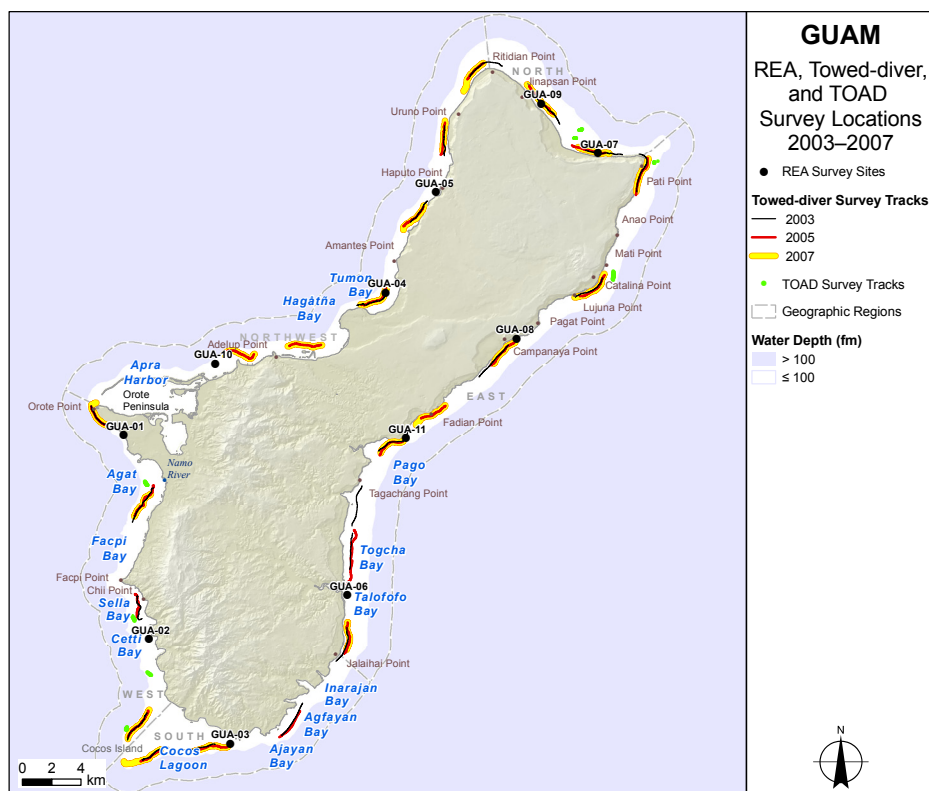
Figure 4.2a. Locations of the REA, towed-diver, and TOAD benthic surveys conducted around Guam during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 5 geographic regions: north, east, south, west, and northwest.

graphic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Guam. Potential reef habitat around this island is represented by a 100-fm contour shown in white on this map.

Benthic habitat mapping data were collected around Guam using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around this island with multibeam sonar covered a total area of 25.7 km^2 in 2003 and 1633 km^2 in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 4.3: "Benthic Habitat Mapping and Characterization."

Information on the condition, abundance, diversity, and distribution of biological communities around Guam was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 4.5–4.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 4.2a, along with their mean depths and total areas or length.

Table 4.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Guam during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	9	9	10
	Mean Depth (m)	12 (SD 1)	12.1 (SD 1.2)	12.1 (SD 1.1)
Benthic	Number of Surveys	9	9	10
	Mean Depth (m)	12 (SD 1)	12.1 (SD 1.2)	12.1 (SD 1.1)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	20	23	19
	Total Survey Area (ha)	49.7	51.2	45.5
	Mean Depth (m)	12.2 (SD 1.8)	16.3 (SD 1.4)	14.8 (SD 1.4)
TOAD		**2003**		
	Number of Surveys	8		
	Total Length (km)	2.49		

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Guam were collected using (1) two types of moored instruments designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water sampling was performed during MARAMP 2005 and 2007 (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). Results for some casts and water samples are not presented in this report because either the data were redundant or erroneous or no data were produced. A summary of deployed instruments and collection activities is provided in Table 4.2b, and results are discussed in Section: 4.4: "Oceanography and Water Quality."

Table 4.2b. Numbers of oceanographic instruments deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Guam during MARAMP 2003, 2005, and 2007. Three types of instruments were moored around Guam: ecological acoustic recorder (EAR), sea-surface temperature (SST) buoy, and subsurface temperature recorder (STR). Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Deepwater CTD cast information is presented in Chapter 3: "Archipelagic Comparisons."

Observation Type	Year						
Instruments	**2003**	**2005**		**2007**		**2009**	**Lost**
	Deployed	**Retrieved**	**Deployed**	**Retrieved**	**Deployed**	**Retrieved**	
SST	1	1	1	1	1	1	–
STR	–	–	3	3	4	4	–
EAR	–	–	–	–	1	1	–
CTD Casts	**2003**	**2005**		**2007**			**Total**
Shallow-water Casts	29	83		44			156
Deepwater Casts	–	6		6			12
Water Samples		**2005**		**2007**			**Total**
		10		13			23

Towed-diver Surveys: Depths

Figures 4.2b–e illustrate the locations and depths of towed-diver-survey tracks around Guam and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

During MARAMP 2003, 20 towed-diver surveys were conducted along the forereef slopes around most of Guam (Figs. 4.2b and c). The mean depth of all survey segments was 12.2 m (SD 1.8), and the mean depths of individual surveys ranged from 8.9 m (SD 3.8) to 16.6 m (SD 2.7).
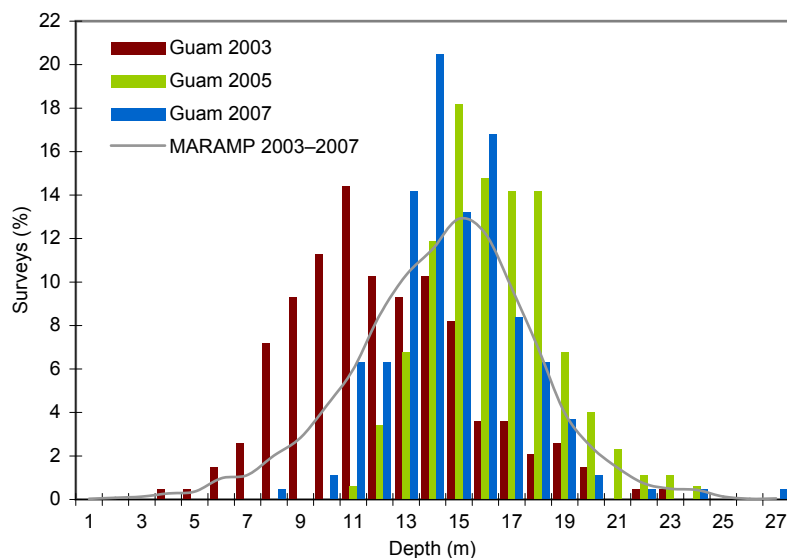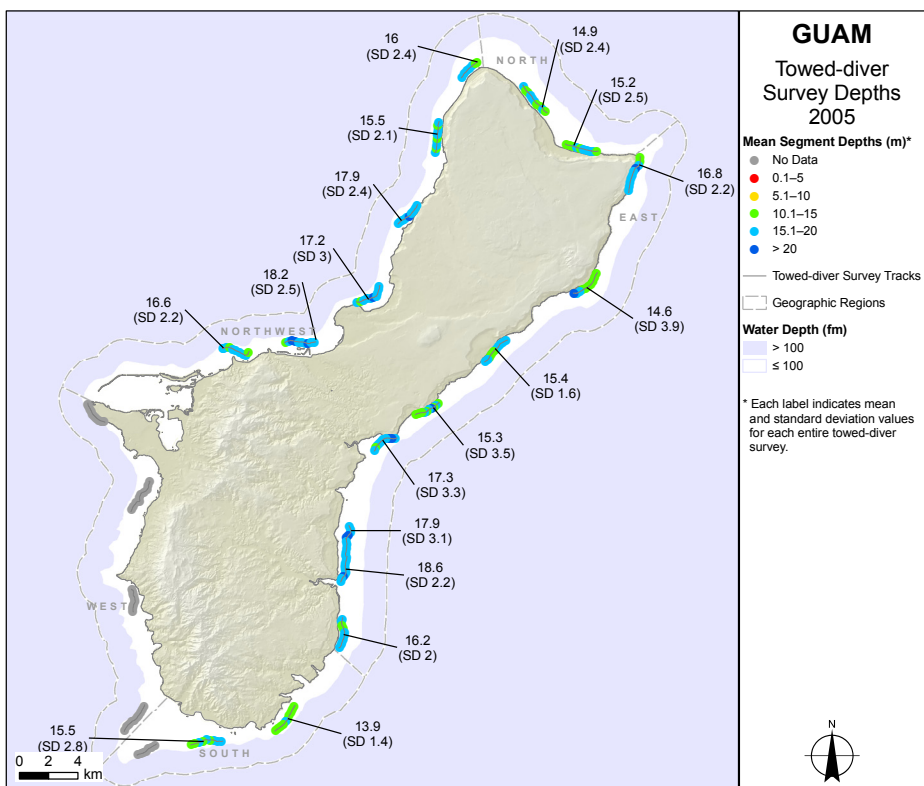

Figure 4.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

Figure 4.2c. Depths and tracks of towed-diver surveys conducted on forereef habitats around Guam during MARAMP 2003. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.
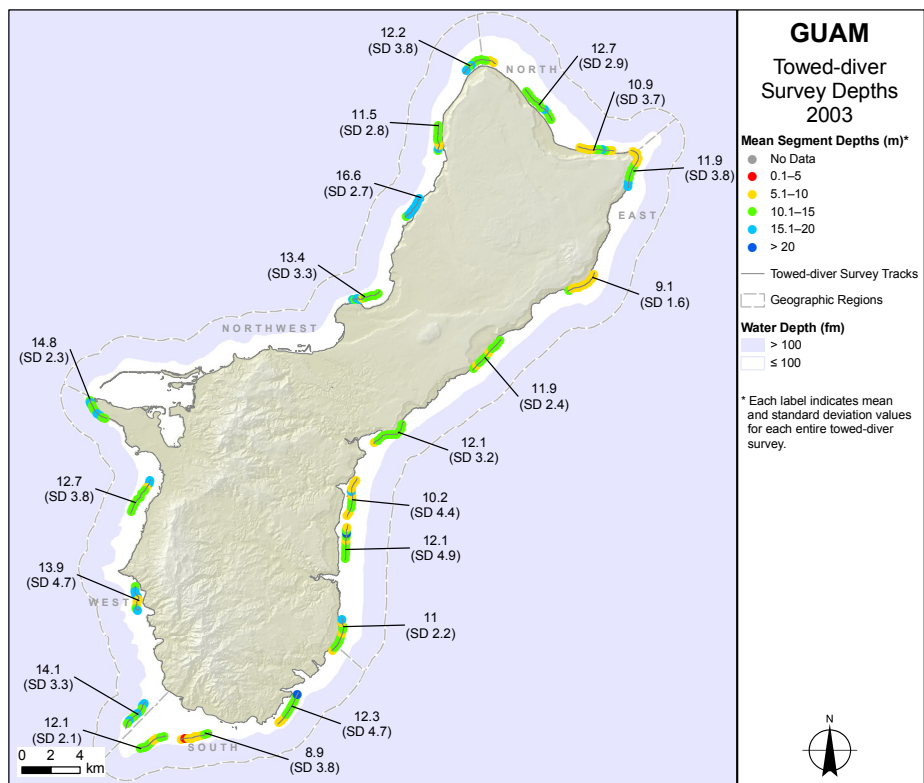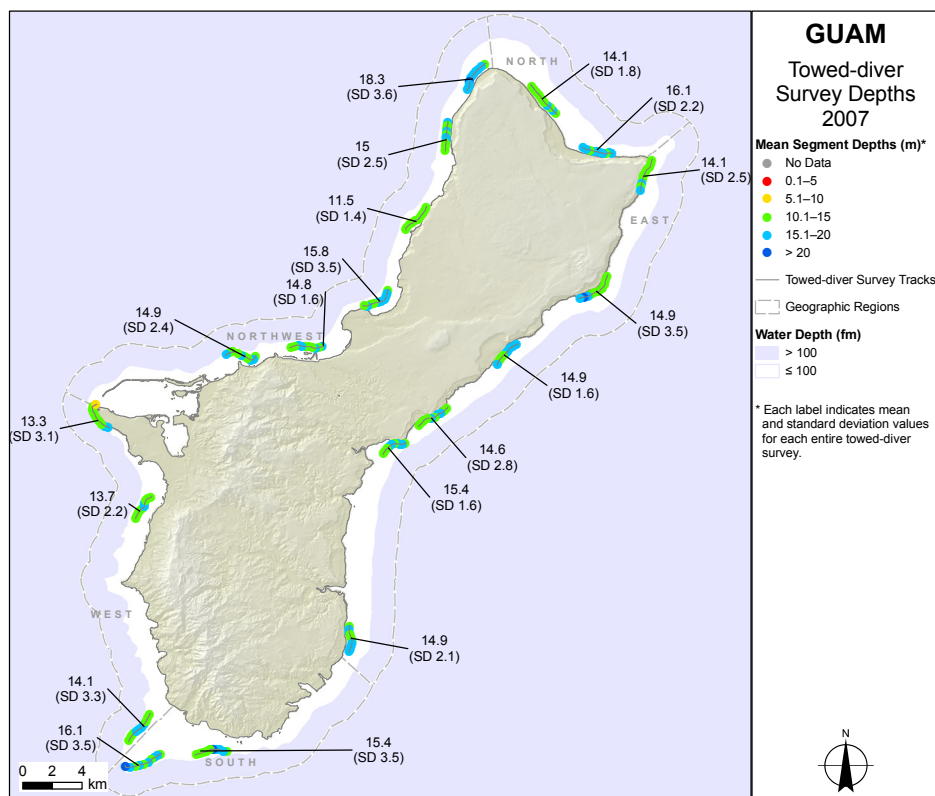

During MARAMP 2005, 23 towed-diver surveys were conducted along the forereef slopes around most of Guam (Figs. 4.2b and d). The mean depth of all survey segments was 16.3 m (SD 1.4), and the mean depths of individual surveys ranged from 13.9 m (SD 1.4) to 18.6 m (SD 2.2). Note: depths were not recorded for 4 surveys in the west region and 1 survey in the south region because of an equipment malfunction.

Figure 4.2d. Depths and tracks of towed-diver surveys conducted on forereef habitats around Guam during MARAMP 2005. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

During MARAMP 2007, 19 towed-diver surveys were conducted along the forereef slopes around most of Guam (Figs. 4.2b and e). The mean depth of all survey segments was 14.8 m (SD 1.4), and the mean depths of individual surveys ranged from 11.5 m (SD 1.4) to 18.3 m (SD 3.6).

GUAM
Towed-diver
Survey Depths
2007

Mean Segment Depths (m)*
- No Data
- 0.1–5
- 5.1–10
- 10.1–15
- 15.1–20
- > 20

— Towed-diver Survey Tracks
- Geographic Regions

Water Depth (fm)
- > 100
- ≤ 100

* Each label indicates mean and standard deviation values for each entire towed-diver survey.

Figure 4.2e. Depths and tracks of towed-diver surveys conducted on forereef habitats around Guam during MARAMP 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

4.3   Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Guam were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~ 5–2500 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted at depths of ~ 10–200 m.

Additional bathymetric data for Guam were obtained from the NOAA Office of Coast Survey (OCS) and the Naval Oceanographic Office (NAVOCEANO). NAVOCEANO collected lidar and singlebeam data over large areas of the inshore waters of Guam in 2001. Later, in 2008, OCS and NAVOCEANO collaboratively surveyed Apra Harbor for the purpose of updating nautical charts. Only bathymetric data and no backscatter data were available from these additional surveys. Therefore, these data could not supplement the multibeam backscatter data collected by the Coral Reef Ecosystem Division (CRED) but have been used in combination with CRED high-resolution multibeam data.

4.3.1   Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 4.3.1a) collected by CRED around Guam during MARAMP 2003 and 2007 encompasses an area of 1659 km².

Multibeam bathymetry acquired around Guam (Fig. 4.3.1a, top panel) emphasizes the distinct seascapes that reflect the different onshore landscapes observed on either side of the Pago-Adelup fault, which runs between Pago Bay and Adelup Point (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). South of the fault, the landscape is characterized by volcanic rock with numerous streams and rivers draining the mountainous topography. North of this fault, the volcanic rock is capped with limestone that ranges from 0 to ~ 500 m in thickness, creating a relatively flat

landscape with little surface water.

As described in Chapter 2: "Methods," Section 2.2.2: "Acoustic Mapping: Bathymetry and Backscatter Derivatives," multibeam backscatter intensity can provide information about the roughness and hardness of the seafloor. Backscatter data acquired around Guam show relatively uniform intensity around the north of Guam with a few notable exceptions
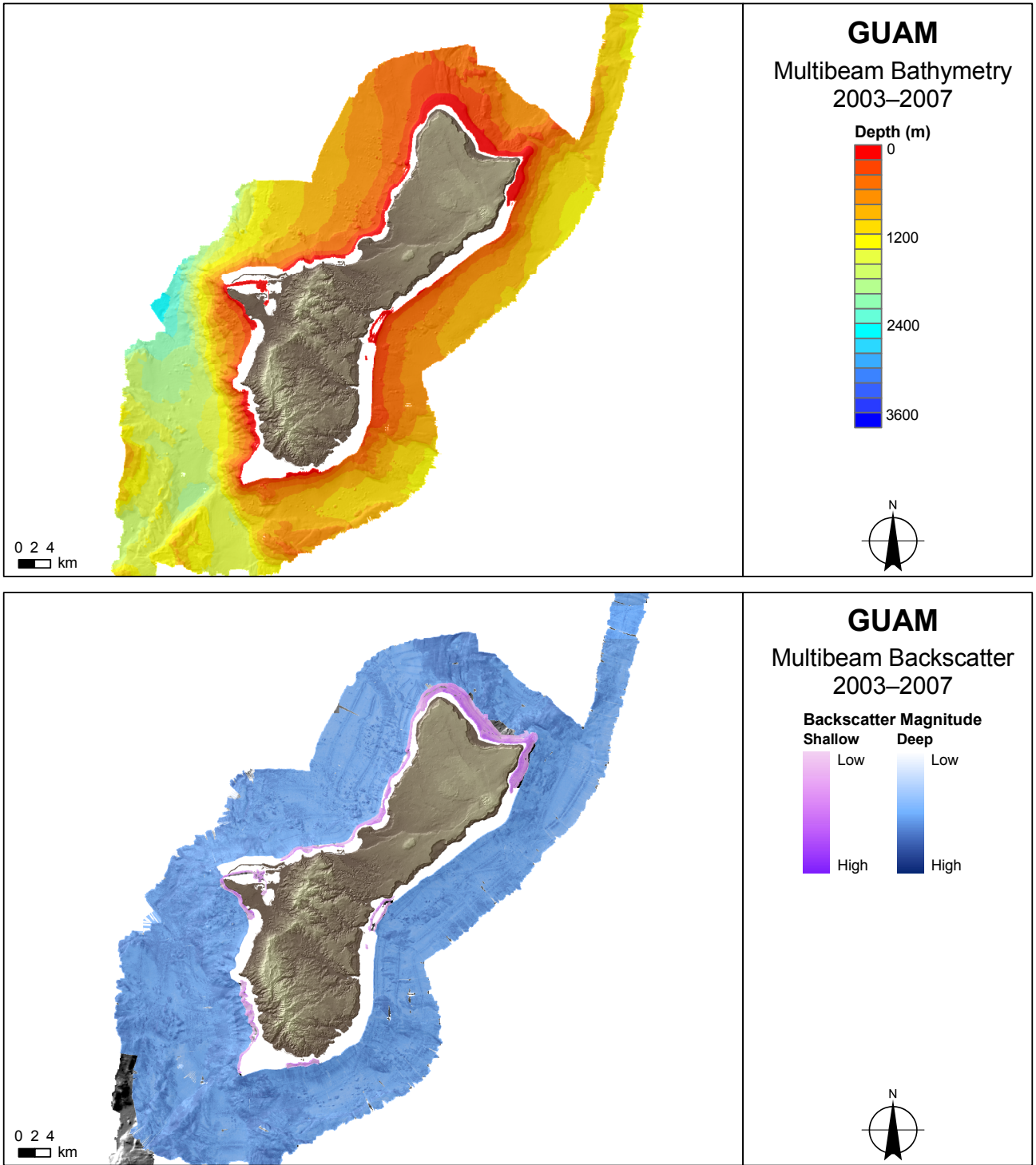
Figure 4.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Guam during MARAMP 2003 and 2007 at depths of ~ 5–2500 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.

(Fig. 4.3.1a, bottom panel). Associated with the erosion deposits to the northwest and the ridge features to the north, distinct patches of high-intensity backscatter are observed. These patches suggest that hard or more rugged substrata may be associated with these topographic features. Similarly, patches of high-intensity backscatter are associated with the more complex bathymetry observed in Agat Bay. Backscatter imagery of the submarine canyons southwest of Guam show a distinct pattern, with low backscatter values within the canyons and higher backscatter values on top of the ridges. Low backscatter values are also seen at the base of the canyons in the deep channel south of Guam.

Bathymetry and Derivatives

The final Guam depth map is a mosaic of multibeam and lidar data obtained from 3 different sources (Fig 4.3.1b). The primary multibeam bathymetry was collected by CRED during MARAMP 2003 and 2007. Shallow-water acquisition on the NOAA R/V *AHI* focused on areas not previously covered by lidar data and on priority areas that were identified by resource management agencies. Thus, data were acquired in 7 key areas: northern Guam (including the Ritidian Unit of the Guam National Wildlife Refuge and Pati Point Preserve), Pago Bay, Ajayan Bay (including Achang Reef Flat Preserve), Cetti Bay, the southern coast of the Orote Peninsula, Apra Harbor, Hagåtña Bay, and Tumon Bay. Full survey coverage of areas deeper than these key areas was achieved from the NOAA Ship *Hi`ialakai* during MARAMP 2007.

Additional multibeam data for Apra Harbor were collected in 2008 by OCS and NAVOCEANO using the U.S. Naval Survey Vessel *Swamp Fox*, fitted with a 455-kHz Reson SeaBat 8125 multibeam echosounder (Naval Oceanographic Office and National Ocean Service 2009).

Bathymetric lidar data and, in waters deeper than ~ 40 m, singlebeam bathymetric data were collected in 2001 by NAVOCEANO (Naval Oceanographic Office 2004). These lidar data were used in areas where no multibeam data were available, primarily in waters shallower than 20 m.
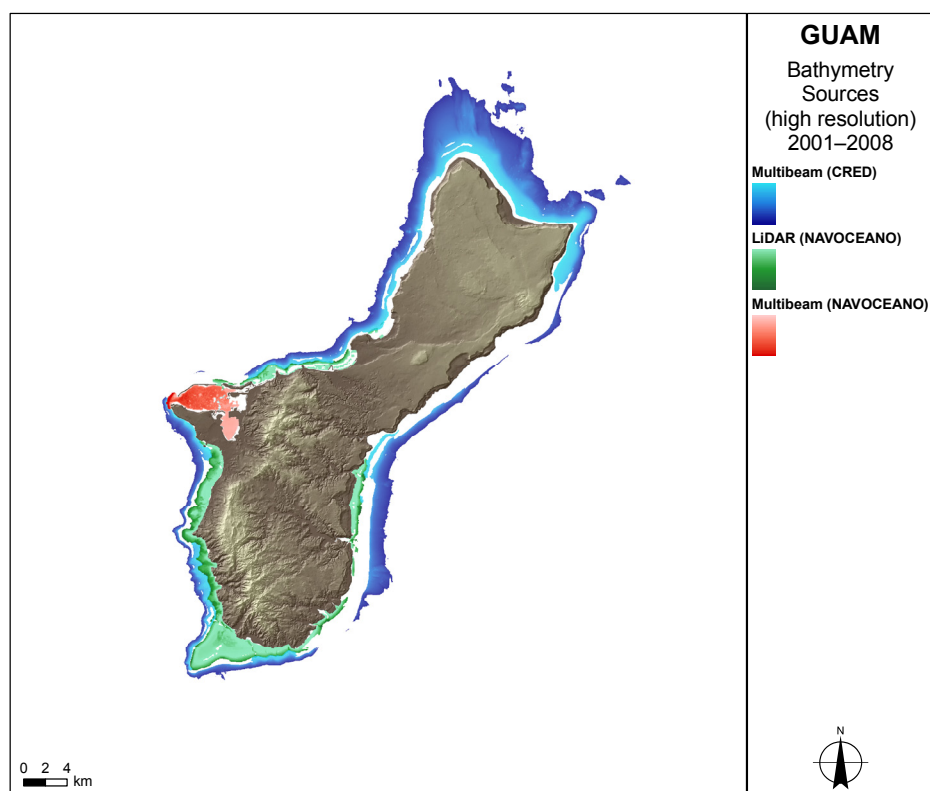
Figure 4.3.1b. Location of multibeam data collected by CRED (shown in blue), multibeam data collected by OCS and NAVOCEANO (shown in red), and lidar and singlebeam data collected by NAVOCEANO (shown in green).

Bathymetric data collected in nearshore (depths of 0–400 m) waters around Guam were combined into a grid at 5-m resolution to allow for the identification of fine-scaled features (Figs. 4.3.1c and f). These high-resolution data were used to derive maps of slope (Figs. 4.3.1d and g) and rugosity (Figs. 4.3.1e and h) for the 4 areas where the greatest coverage was achieved. Slope and rugosity around the whole island were derived from the 60-m bathymetric grids (Figs. 4.3.1i and j). Bathymetric position index (BPI) zones (Fig. 4.3.1k) were derived from the 60-m grid. Together, these maps provide layers of information to characterize the benthic habitats around Guam.

The 3 ridges extending north from Ritidian Point are shown in detail on the high-resolution bathymetry and slope maps (Figs. 4.3.1c and d, top panels) that highlight the steep slopes on the east side of these ridges. The shallow pavement on the north coast has several successively deeper platforms, the edges of which are identified by increased slope relative to their surrounding platforms. Steep slopes are also associated with areas of erosional debris in deep waters around Guam. The highest levels of rugosity (Fig. 4.3.1e, top panel) appear associated with the steepest slopes, suggesting that the topography in these areas may be rougher than in areas where slopes are less steep—although the high-rugosity values are also influenced by the slope itself.
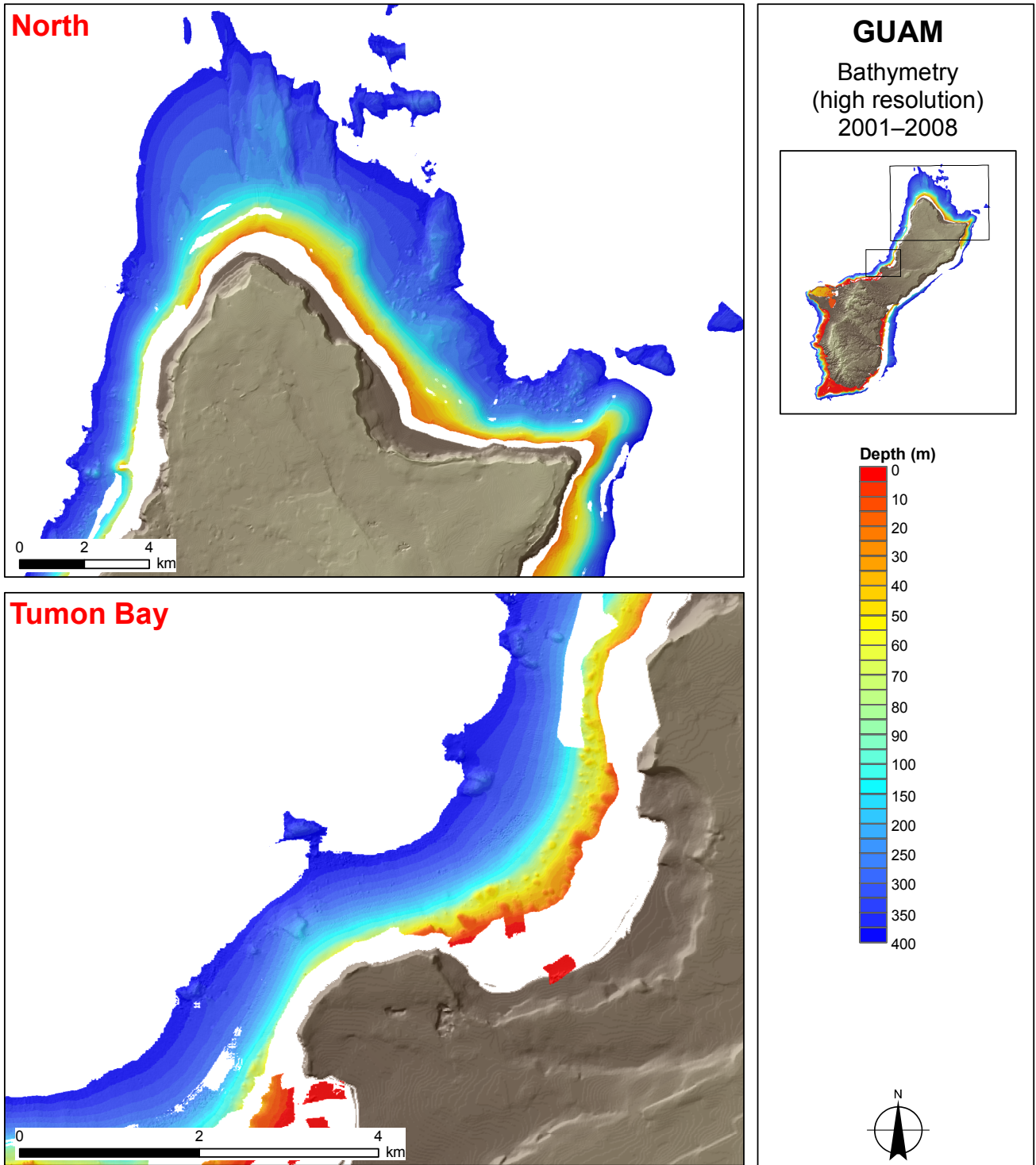
Figure 4.3.1c. High-resolution bathymetry (grid cell size: 5 m) collected between 2001 and 2008 (*top*) around north Guam and (*bottom*) in Tumon Bay.

Bathymetry (Fig. 4 3.1.c, bottom panel) within Tumon Bay shows that the shallowest mapped seabed is characterized by a series of spurs, the edges of which are delineated by their slopes and high rugosity (Figs. 4 3.1.d and e, bottom panels). The slope and rugosity maps reveal numerous small mounds.
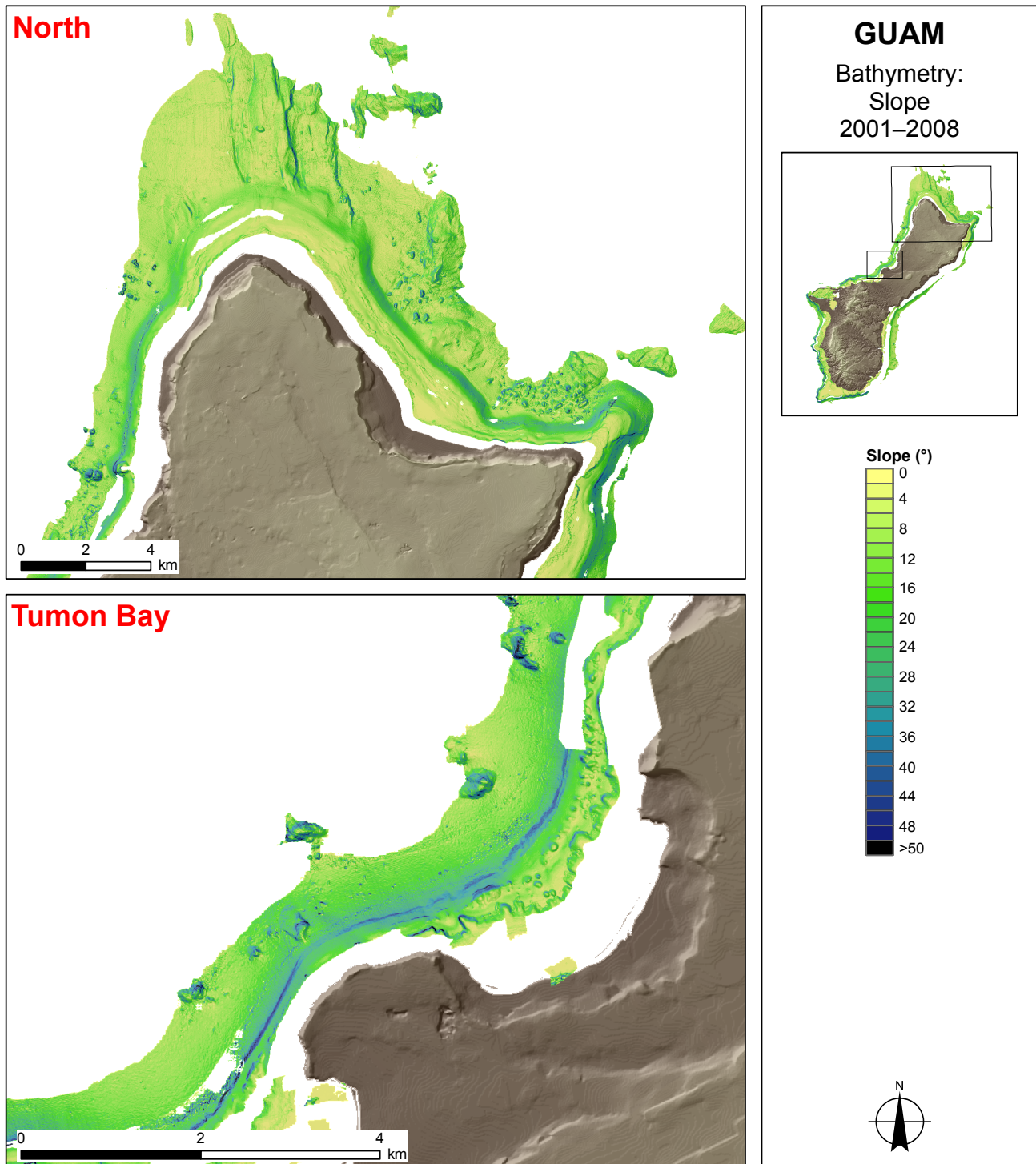
Figure 4.3.1d. Slope (°) of 5-m bathymetric grid (*top*) around north Guam and (*bottom*) in Tumon Bay. Derived from data collected between 2001 and 2008, these maps reflect the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest blue shades and the flattest areas in yellow shades.

North

Tumon Bay

GUAM
Bathymetry:
Rugosity
2001–2008

Rugosity
High

Low

N
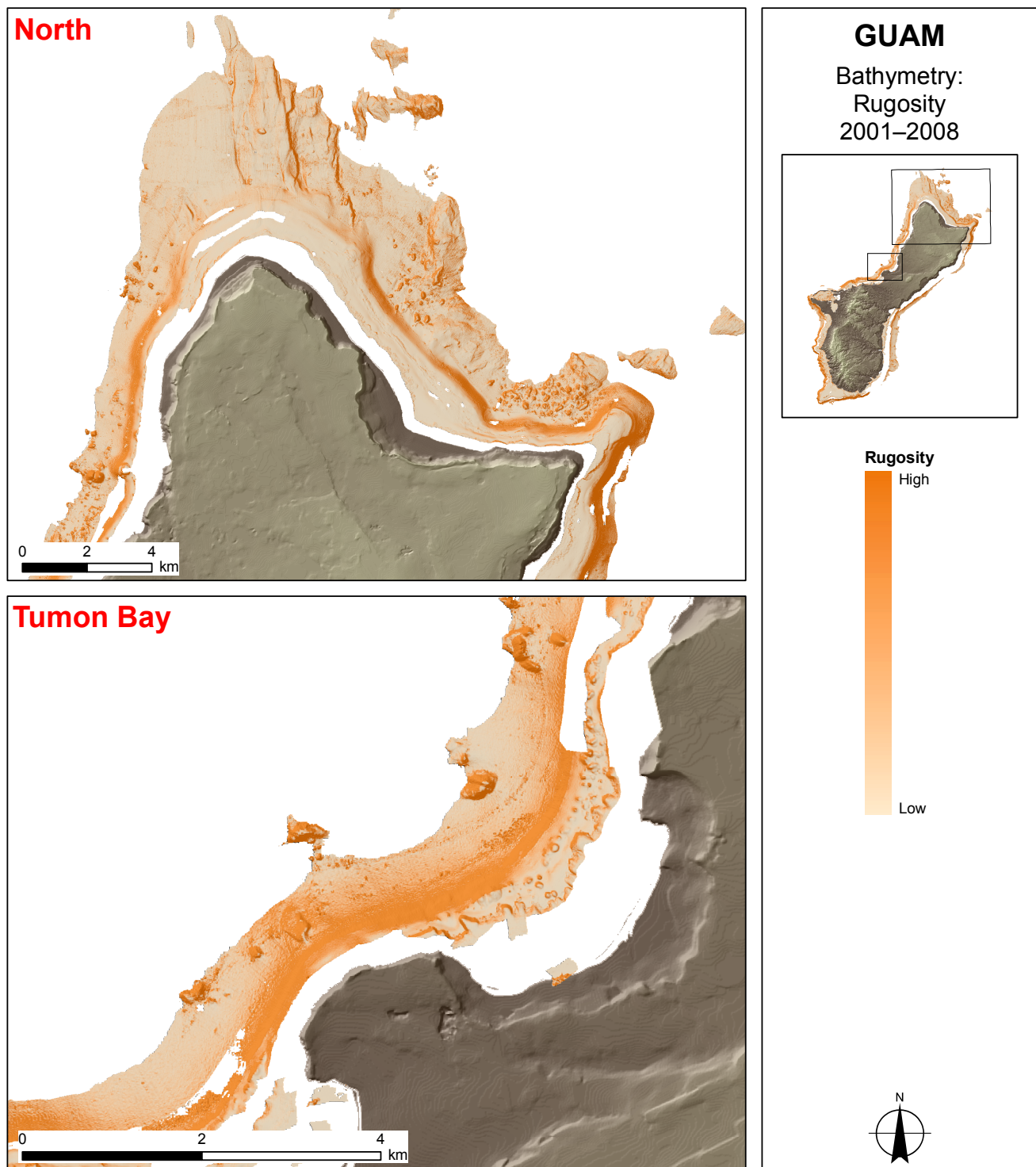
Figure 4.3.1e. Rugosity of 5-m bathymetric grid (*top*) around north Guam and (*bottom*) in Tumon Bay. Derived from data collected between 2001 and 2008, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness. Dark shades represent high rugosity and light shades represent low rugosity.

High-resolution bathymetric data acquired within Apra Harbor and along the south coast of the Orote Peninsula reveal some interesting topographic features. Within Apra Harbor, the available bathymetric data show numerous mounds up to 300 m in diameter (Fig. 4.3.1f, top panel), the edges of which are particularly accentuated by their high slopes in an otherwise naturally flat area of seabed, in contrast to the actively dredged areas of seabed within the inner harbor where no such mounds are found (Fig. 4.3.1g, top panel). Along the south coast of the Orote Peninsula, a number of narrow platforms are separated by very steep slopes. Within this area of interest, the BPI terrain analysis identifies very few areas of flat seabed, and the data as a whole suggest an area of high topographic complexity (Fig. 4.3.1k).

Lidar bathymetry of Cocos Lagoon suggests that much of the seabed within this lagoon is very shallow with depths < 2 m (Fig. 4.3.1f, bottom panel) and flat (Fig. 4.3.1g, bottom panel) with low rugosity (Fig. 4.3.1h, bottom panel). In the inner part of this lagoon, a deeper basin has depths of 4–8 m and mounds rising steeply to near the surface; this area in the north part of this lagoon can best be identified in the bathymetry (orange shades in Fig. 4.3.1f, bottom panel) and slope (Fig. 4.3.1g, bottom panel) plots. Within this area, 2 even deeper depressions have depths of 12–13 m. North of Cocos Lagoon, there is a series of submarine canyons. The slope and rugosity maps highlight very steep slopes along the canyon edges and a complex and rugged topography along the top of the canyons and on the ridges. These observations are supported by the BPI terrain analysis that reveals a seafloor landscape primarily characterized by slopes, ridges, and depressions (Fig.
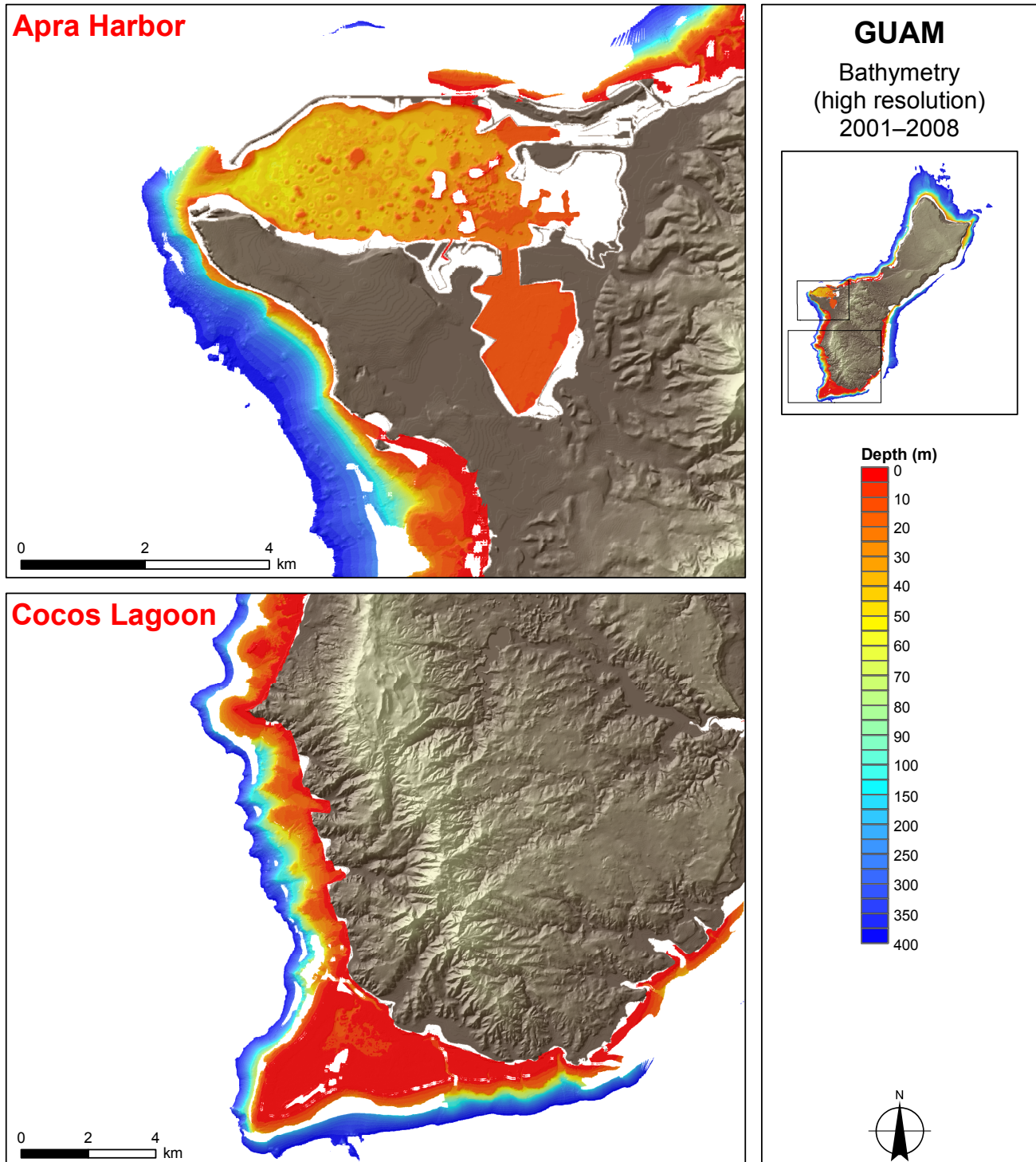
Figure 4.3.1f. High-resolution bathymetry (grid cell size: 5 m) collected between 2001 and 2008 within (*top*) Apra Harbor and (*bottom*) Cocos Lagoon.

4.3.1k). South of Cocos Lagoon, the high-resolution slope map shows a series of narrow flat platforms separated by steep slopes. Low rugosity values are observed on the top of these platforms with higher rugosity values on the slopes.
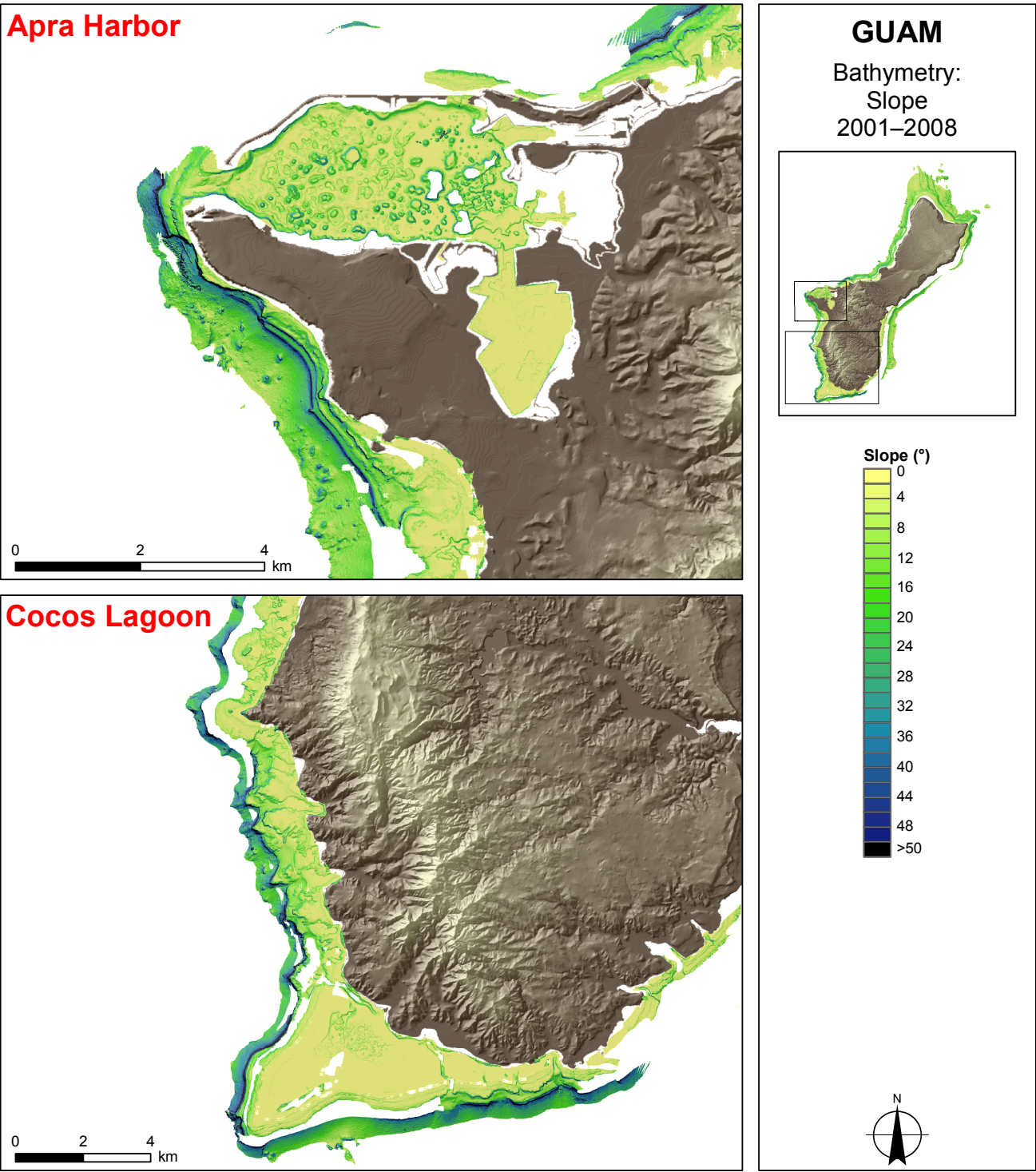

Figure 4.3.1g. Slope (°) of 5-m bathymetric grid within (*top*) Apra Harbor and (*bottom*) Cocos Lagoon. Derived from data collected between 2001 and 2008, these maps reflect the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest blue shades and the flattest areas in yellow shades.
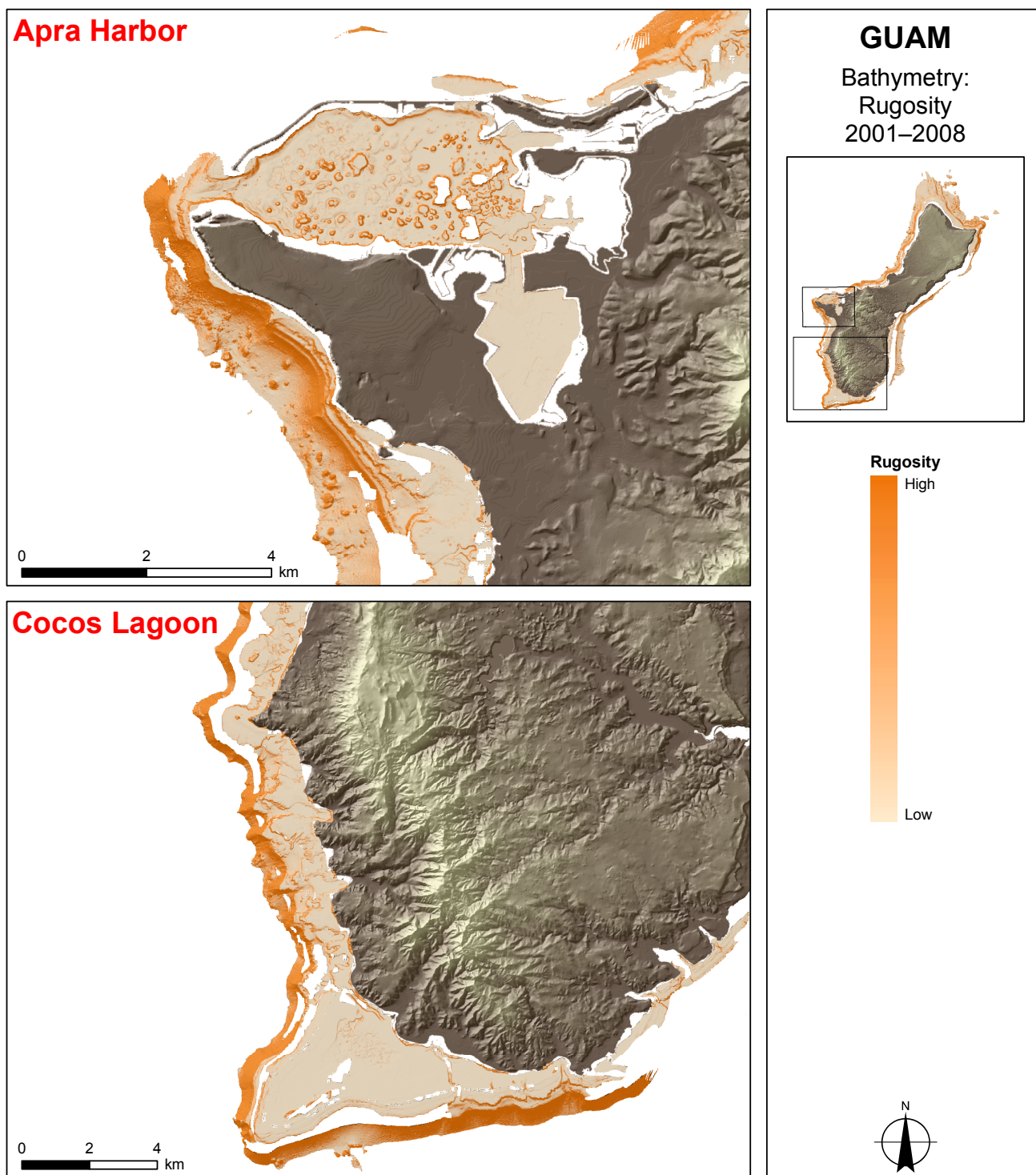
Figure 4.3.1h. Rugosity of 5-m bathymetric grid within (*top*) Apra Harbor and (*bottom*) Cocos Lagoon. Derived from data collected between 2001 and 2008, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness. Dark shades represent high rugosity and light shades represent low rugosity.

Slope and rugosity, derived from the low-resolution bathymetry data (60-m bathymetric grid), both highlight the different characters of the benthic habitats north and south of Guam that are also reflected in the onshore geology. The slope and rugosity maps (Figs. 4.3.1i and j) reveal a relatively flat, low-rugosity seabed around northern Guam, with very few steep slopes recorded, other than around Pati Point. Around southern Guam, the seabed topography is more varied with many areas of high slope and rugosity, particularly around the submerged canyons in Cetti Bay. Maximum recorded slopes are 50°–55°.

Figure 4.3.1i. Slope (°) of 60-m bathymetric grid around Guam. Derived from data collected between 2003 and 2007, these maps reflect the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest blue shades and the flattest areas in yellow shades.
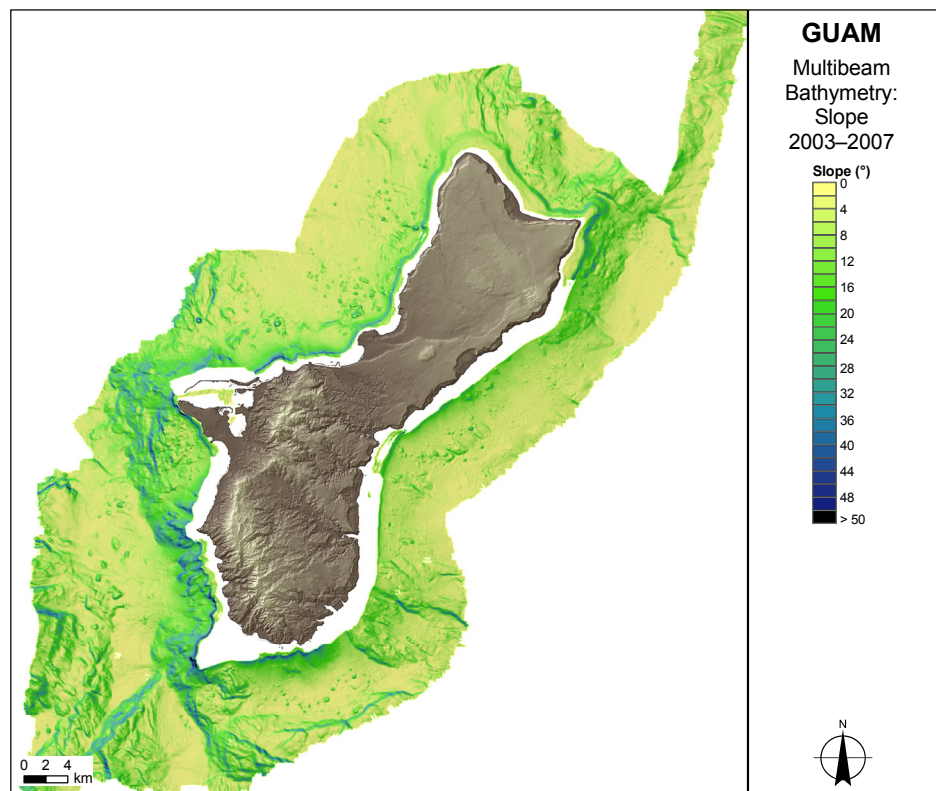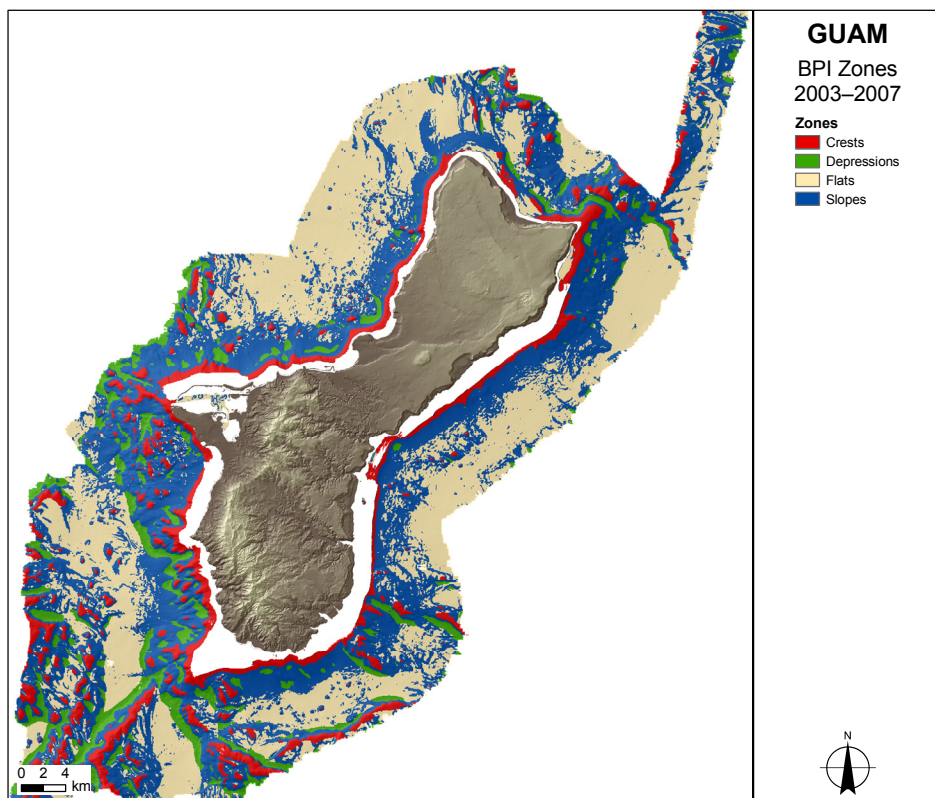

Figure 4.3.1j. Rugosity of 60-m bathymetric grid around Guam. Derived from data collected between 2003 and 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness. Dark shades represent high rugosity and light shades represent low rugosity.
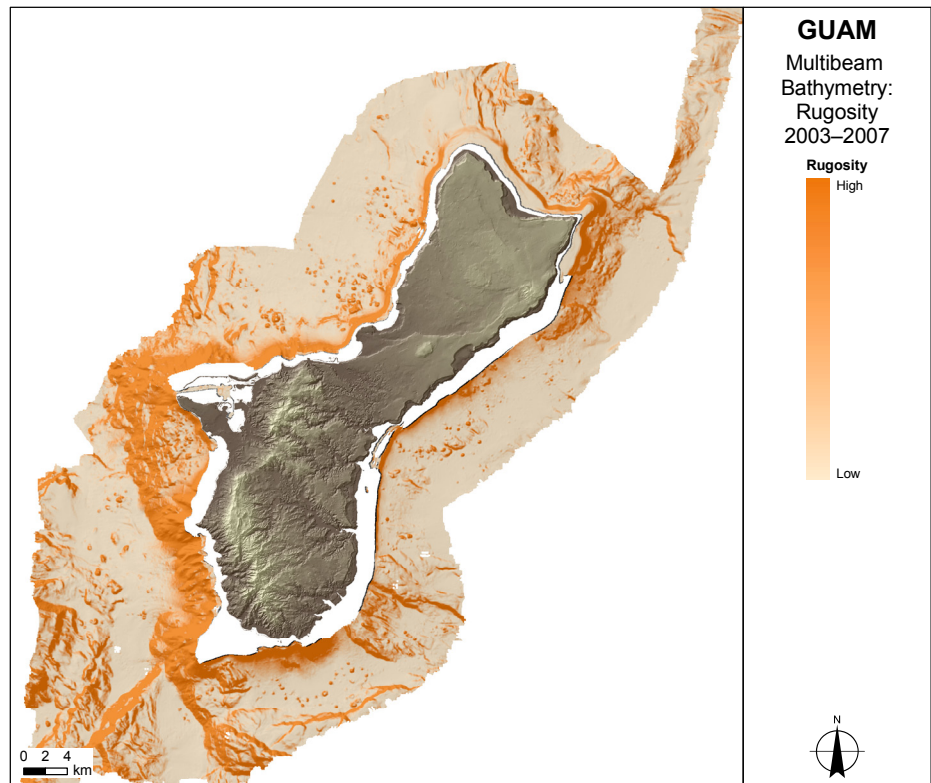
The patterns revealed by the slope and rugosity maps are supported by what the BPI zones map (Fig. 4.3.1k) shows: the seabed around northern Guam is characterized predominantly by flats with slopes found close to shore. In the shallowest waters surveyed, the BPI analysis identifies reef crests. However, this classification is likely an artifact of the methodology, since no data are available for immediately inshore areas and no comparison can be made to the innermost cells of the grid. Instead, these areas probably should be characterized as slopes.

The seabed around southern Guam has a much more varied terrain, with a mixture of slopes, crests, and depressions associated with canyons and ridges. At the base of these slopes, a flat area corresponds to the deep channel identified in the multibeam bathymetry.

GUAM
BPI Zones
2003–2007

Zones
- Crests
- Depressions
- Flats
- Slopes

0 2 4
km

N

Figure 4.3.1k. BPI Zones of 60-m bathymetric grid around Guam derived from data collected between 2003 and 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—have been used in this analysis.

High-resolution Multibeam Backscatter and Derivatives

Because very little multibeam data were acquired in shallow water, discussion of the high-resolution backscatter data is limited here to 3 areas of interest: north Guam, Apra Harbor, and Cocos Lagoon. Since no obvious artifacts are observed within the very limited data collected, all of the shallow backscatter data were used to generate the hard–soft substrate map, and no clipping of the data was performed.

In northern Guam, high-intensity backscatter values that suggest a hard seafloor are seen along the top of the shallow shelf, and moderate backscatter values suggest increased sediments on the adjoining slopes (Fig. 4.3.1l, top panel). Where the seabed plateaus at a depth of ~ 200 m, low-intensity backscatter values suggest sediment areas. This distinction between the soft seabed in deep areas and the hard seabed on the shallow shelf and slope is reflected in the hard–soft classification (Fig. 4.3.1m, top panel). Low-intensity backscatter values are seen in a channel at the center of Jinapsan Beach, presumably a result of accumulated sediment lining the floor of the channel.

The hard–soft classification suggests that Apra Harbor is characterized by a mixture of hard and soft substrate, and the mound features seen in the slope map are generally characterized by hard substrate (Fig. 4. 3.1m, middle panel). South of Orote Peninsula, high backscatter values are observed on the shallow shelf area with lower values on the slopes. This pattern is shown on the hard–soft substrate map, suggesting a hard and shallow shelf descending to sediment-covered slopes.

Around the submerged canyons north of Cocos Lagoon, high-resolution backscatter data reveal high backscatter values on the canyon ridges and low values within the canyon gullies (Fig. 4. 3.1l, bottom panel). The hard–soft substrate map more clearly highlights this pattern of hard and soft substrates alternating between the ridges and gullies (Fig. 4. 3.1m, bottom panel). This pattern is likely caused by downward transport and accumulation of sediments within the canyons. Along the south coast, as in other parts of this island, the shallow shelf is characterized by high-intensity backscatter indicative of hard substrates, whereas the deeper slopes are characterized by low-intensity backscatter indicative of soft substrates.
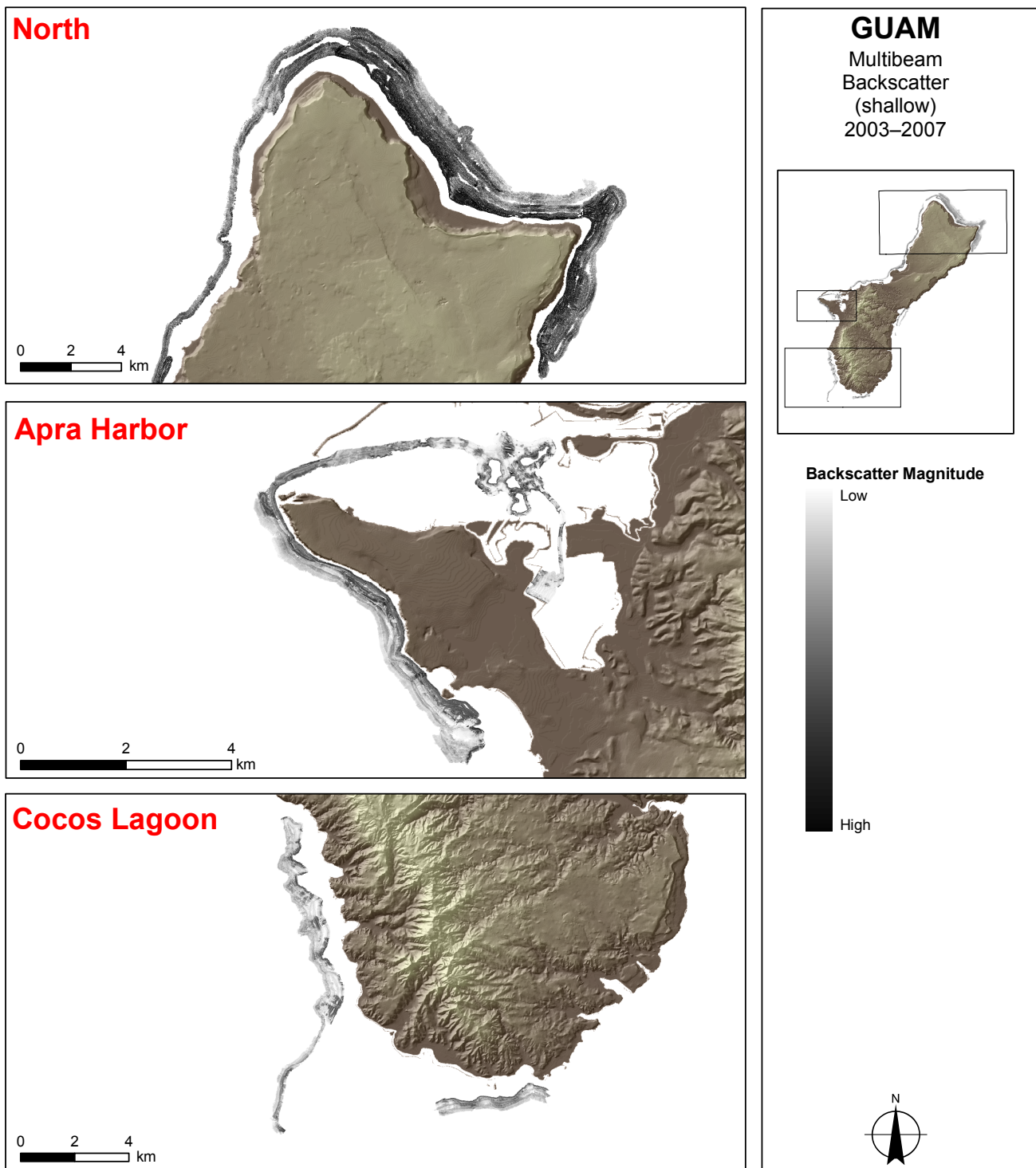
GUAM

Figure 4.3.1l. Gridded, high-resolution, multibeam backscatter data (grid cell size: 5 m) collected within 3 areas of interest around Guam during MARAMP 2003 and 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates.
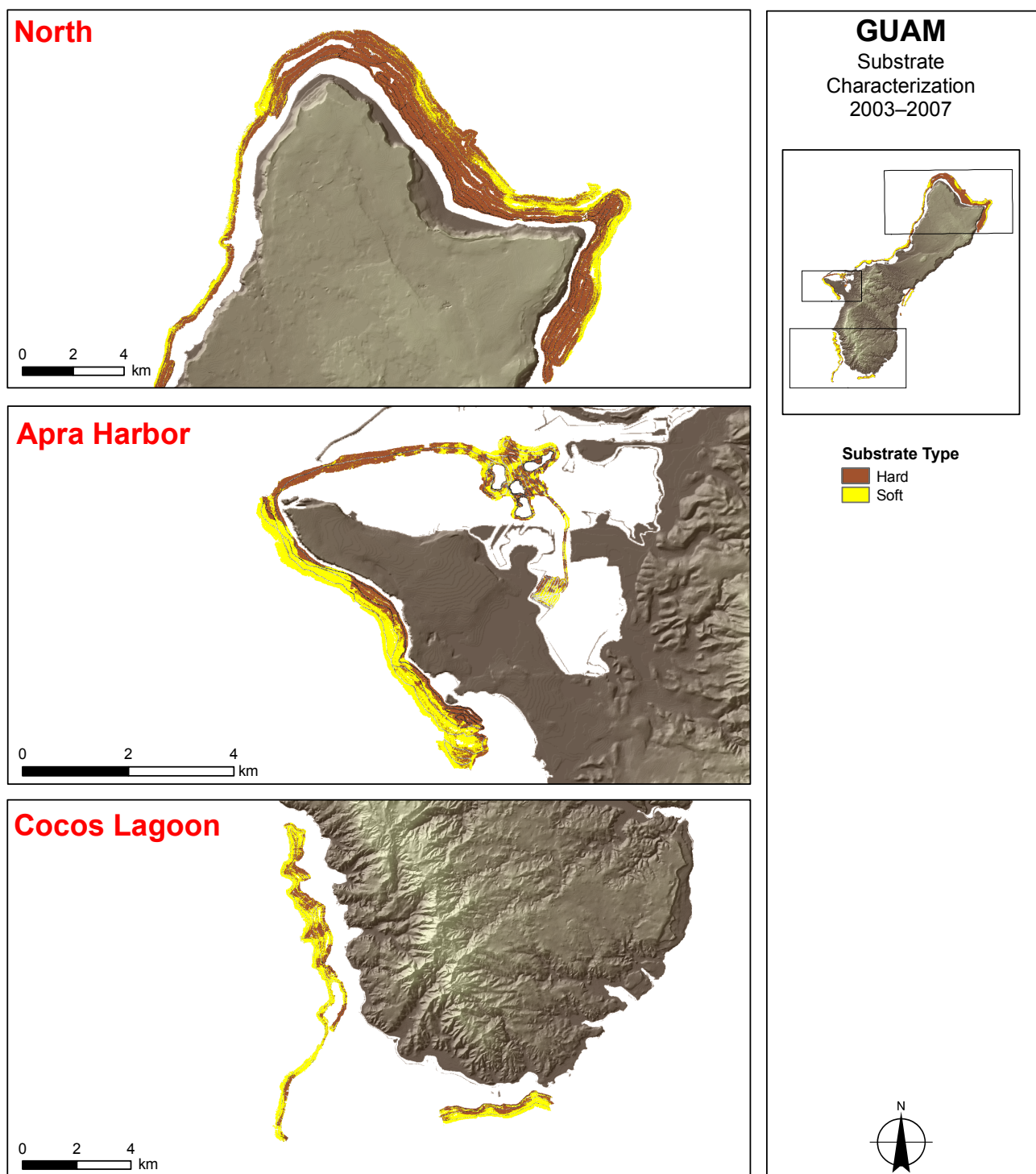
Figure 4.3.1m. Hard and soft substrates (grid cell size: 5 m) around or in (*top*) north Guam, (*middle*) Apra Harbor, and (*bottom*) Cocos Lagoon, based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Guam between 2003 and 2007.

4.3.2 Optical Validation

During MARAMP 2003, 8 TOAD optical-validation surveys were conducted around Guam at depths of 15–200 m (Fig. 4.3.2a). Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live-hard-coral cover.

Covering a distance of 146 km at depths of 4–27 m, 62 towed-diver optical-validation surveys of forereef habitats were conducted around Guam during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

Figure 4.3.2a. Towed-diver tracks from surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007 and TOAD camera-sled tracks for MARAMP 2003. Survey tracks are displayed over the multibeam hard–soft substrate map. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.
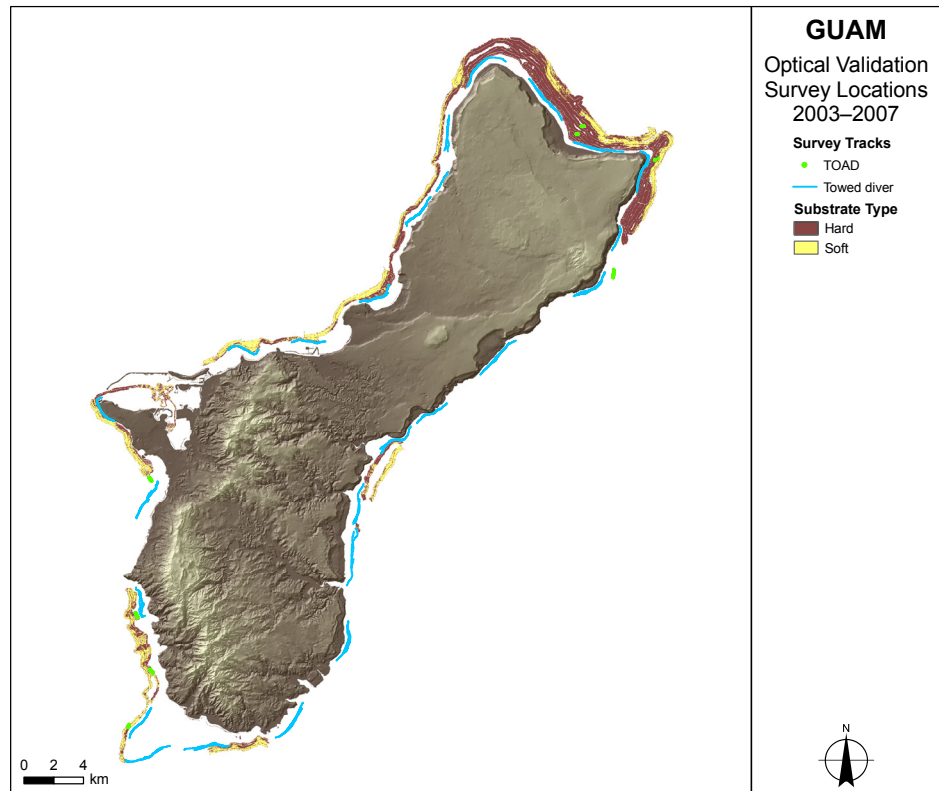
4.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Guam are discussed in this section. These descriptions are organized by the 5 geographic regions around Guam, beginning with the north region and moving clockwise. Sand cover observed by towed divers around Guam was low in most areas suggesting predominantly hard-substrate habitats in the nearshore environment; however, discrete patches of higher sand cover were noted at the mouths of some rivers (Fig. 4.3.3a). The extent to which these hard substrates supported live hard corals was variable (Fig. 4.3.3c). Habitat complexity around Guam was less variable, since it was predominantly classified as ranging from medium-low to medium-high; some areas outside of this range are noted later (Fig. 4.3.3b). The remainder of this section provides more detail about habitat complexity, live coral cover, and sand cover.

The habitats of low to medium complexity observed by towed divers around northern Guam were characterized by moderately low sand cover (< 30%). Higher sand cover was observed around Ritidian Point in the north region in an area of very low live coral cover. The highest levels of coral cover observed in this region were off Jinapsan Point and within the large bay to the east where interpolated live-coral-cover values of up to 62.5% were recorded. TOAD surveys were conducted in deeper waters north of this patch of high coral cover, but analyses of this acquired video suggested that there was no live coral cover and that the seabed was composed of unconsolidated sediment with macroalgae.

North of Pago Bay in the east region of Guam, habitats of medium-low to medium-high complexity were predominantly characterized by low sand cover with low cover of live corals. High sand cover was observed by towed divers at and just south of Campanaya Point. The highest coral cover within this area was around Catalina Point, where interpolated live coral cover reached 62.5%. Because it was not possible to fully classify video from the 2 TOAD surveys conducted off Pati Point, the sediment observed in that video footage was described as unconsolidated, but it was not possible to further discriminate the nature of this sediment. Live coral cover observed in video from these surveys was 40.1%–60% at a depth of ~ 55 m.
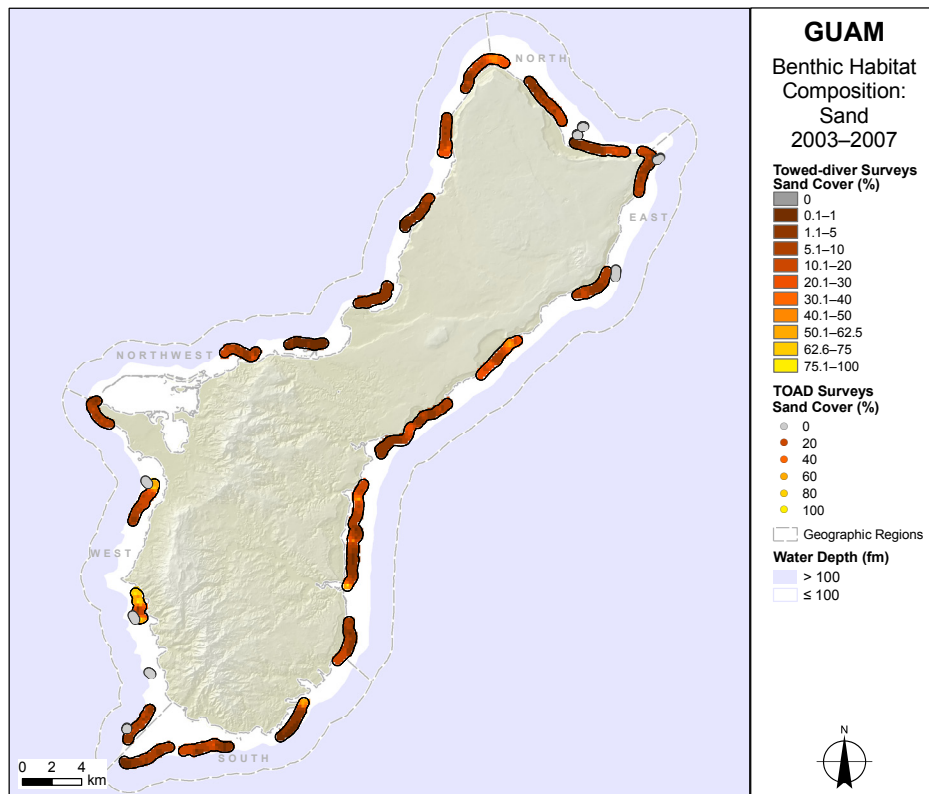
Figure 4.3.3a. Observations of sand cover (%) from towed-diver surveys of forereef habitats conducted and analysis of TOAD video collected around Guam during MARAMP 2003, 2005, and 2007.

From Pago Bay south to Agfayan Bay, live coral cover observed by towed divers was higher (10.1%–62.5%), in an area of low sand cover and habitat of medium-high complexity. In the south region, around the forereef of Cocos Lagoon, habitats of low to medium-low complexity support moderate cover of live corals (5.1%–50%).
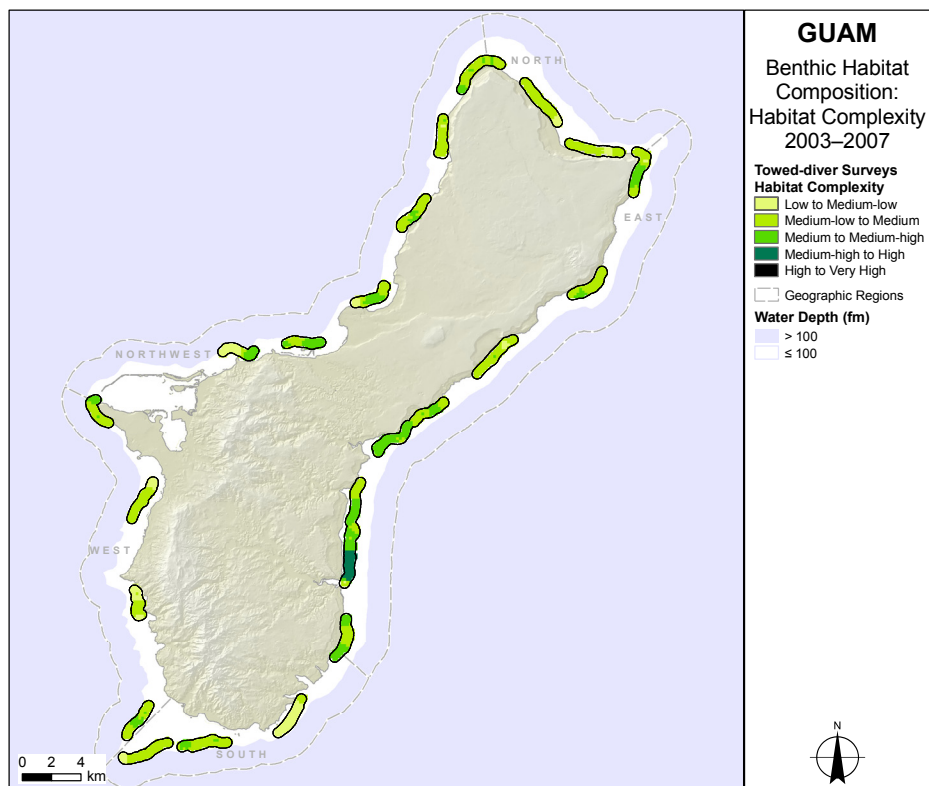

Figure 4.3.3b. Observations of benthic habitat complexity from towed-diver surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007.

Live coral cover observed by towed divers in the west region was consistently < 20%, and habitats there had low to medium complexity and were a mixture of hard and soft sediment with the sandiest areas found at the mouth of Namo River and within Sella Bay. The soft sediment habitat observed by Namo River was not seen in the TOAD video obtained farther offshore at depths of 16–32 m, where sand cover was 0% and the habitats encountered were predominantly characterized by hard substrates. No live coral cover was observed within this TOAD video footage. Analyses of video from a TOAD survey made within Sella Bay showed mixed substrates, with 3 video frames at depths of 28 m, 43 m, and 50 m suggesting that live coral cover was 20% there. Analyses of video footage from 2 TOAD surveys conducted in Cetti Bay and west of Cocos Lagoon at depths of 42–204 m suggested no live coral cover, and substrates there were mainly classified as 100% unconsolidated sediment, as video quality precluded distinguishing between sand and other unconsolidated sediments.

In the northwest region, habitat complexity recorded by towed divers was predominantly categorized as medium-low to medium. Very low sand cover was observed, and coral cover was variable, with interpolated live coral cover ranging from 0.1%–1% to 40.1%–50%, with the highest levels recorded south of Haputo Point.

Figure 4.3.3c. Cover (%) observations of live hard corals from towed-diver surveys of forereef habitats conducted and analysis of TOAD video collected around Guam during MARAMP 2003, 2005, and 2007.
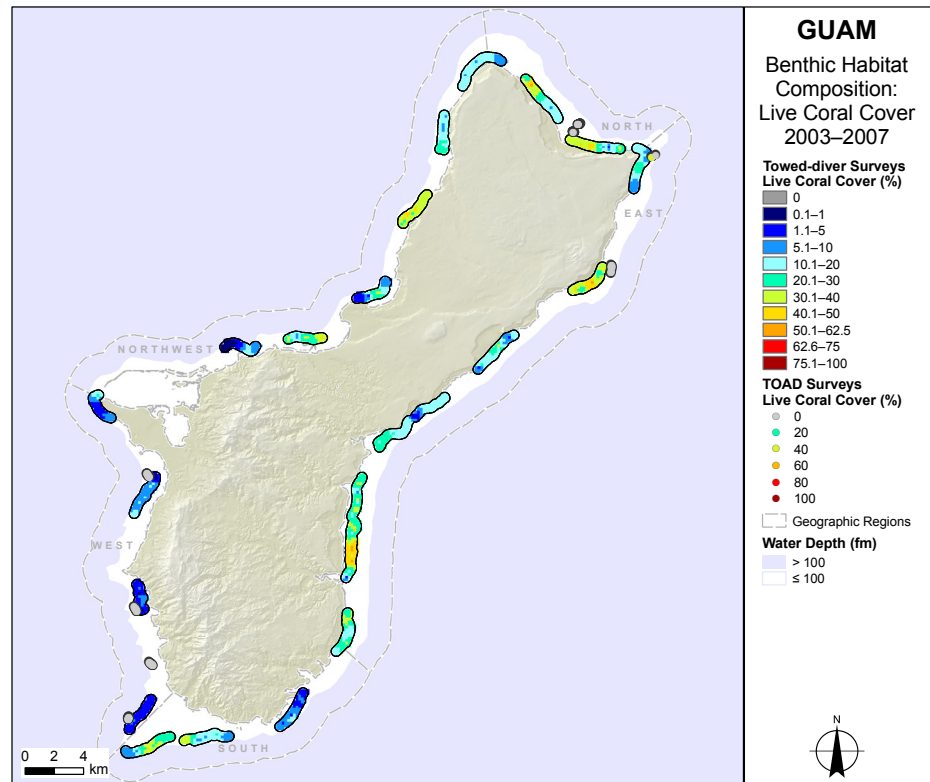

4.4   Oceanography and Water Quality

4.4.1   Hydrographic Data
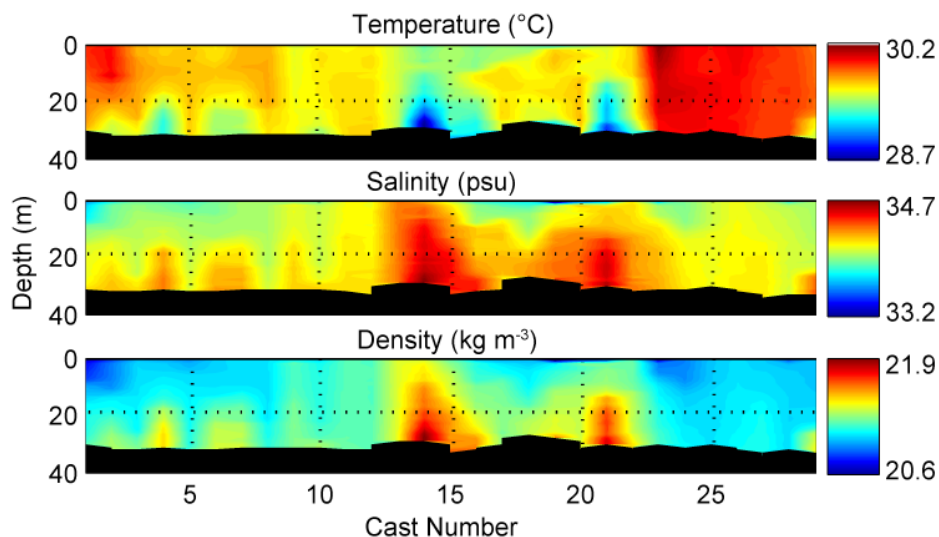
2003 Spatial Surveys

During MARAMP 2003, 29 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters at the island of Guam over the period of September 22–25. Temperature, salinity, and density values from these casts varied both spatially and vertically. Spatial comparisons of water properties at a depth of 10 m suggest a moderate range in temperature (0.68°C) values, with waters in the west and northwest regions warmer than waters in the north and

east regions (Fig. 4.4.1a). Vertical comparisons of CTD profiles (Fig. 4.4.1b) reveal water properties with broad ranges in temperature (1.5°C), salinity (1.5 psu), and density (1.3 kg m^{-3}) values. Two areas with cool temperature (~ 28.7°C), high salinity (~ 34.7 psu), and high density (~ 21.9 kg m^{-3}) values, relative to other cast locations at Guam, were recorded: one at the northeast end of this island near Pati Point (casts 12–15) and the other also in the east region but farther south (casts 17–22, for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). Both of these cool areas likely were formed by local upwelling processes. Mild vertical mixing by easterly trade winds of relatively cool, saline, and turbid waters was apparent along the entire east region. The highest temperatures from CTD casts at Guam of ~ 30.2°C—corresponding with relatively low salinities of ~ 34 psu and low densities of ~ 21 kg m^{-3}—were recorded in the west region (casts 23–27) in Cetti, Sella, and Facpi Bays and in Apra Harbor in the northwest region (cast 1). In these areas, sheltered from easterly winds by the mountains in the south of Guam, vertical mixing upward of deeper, cooler subsurface waters did not occur.
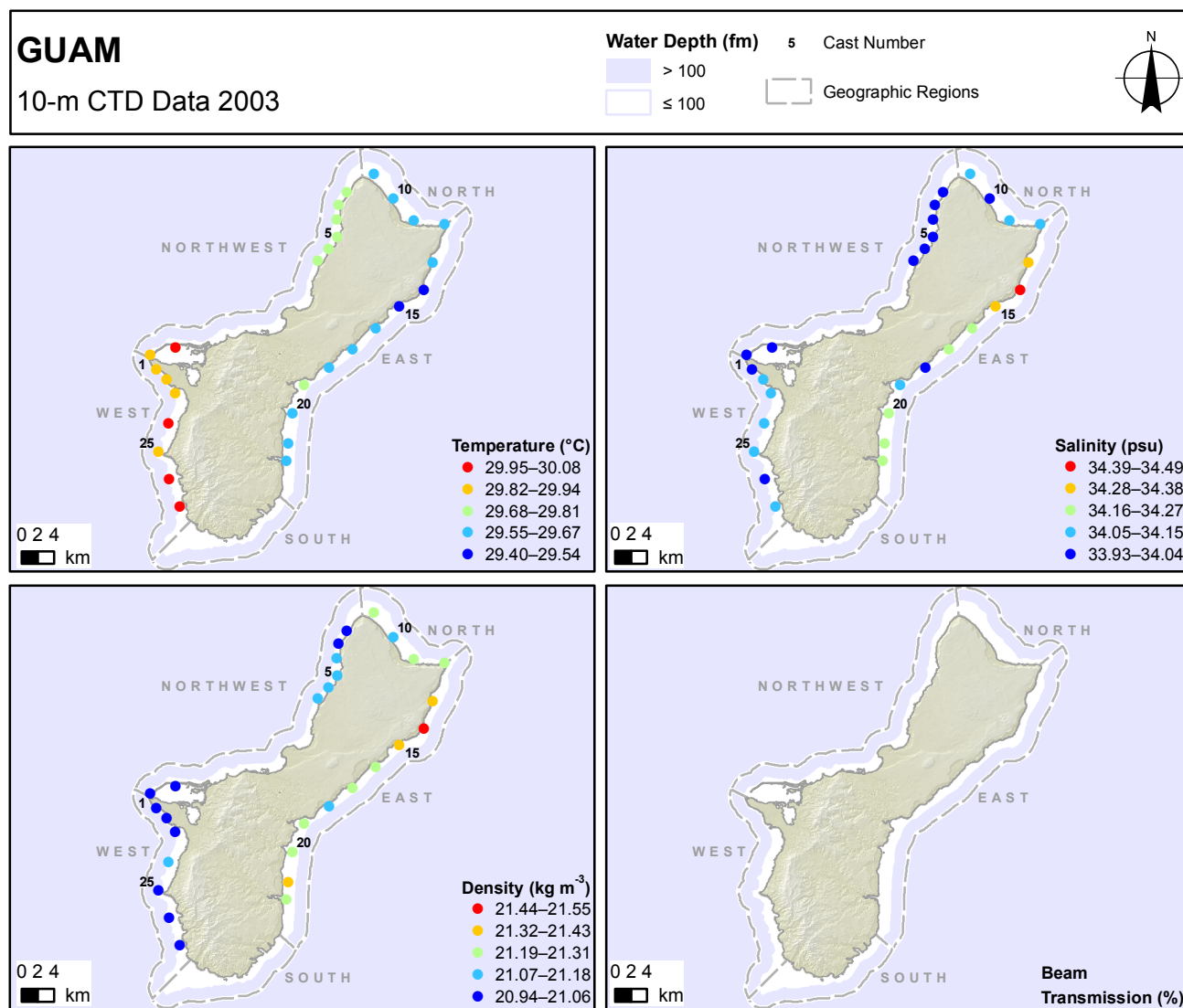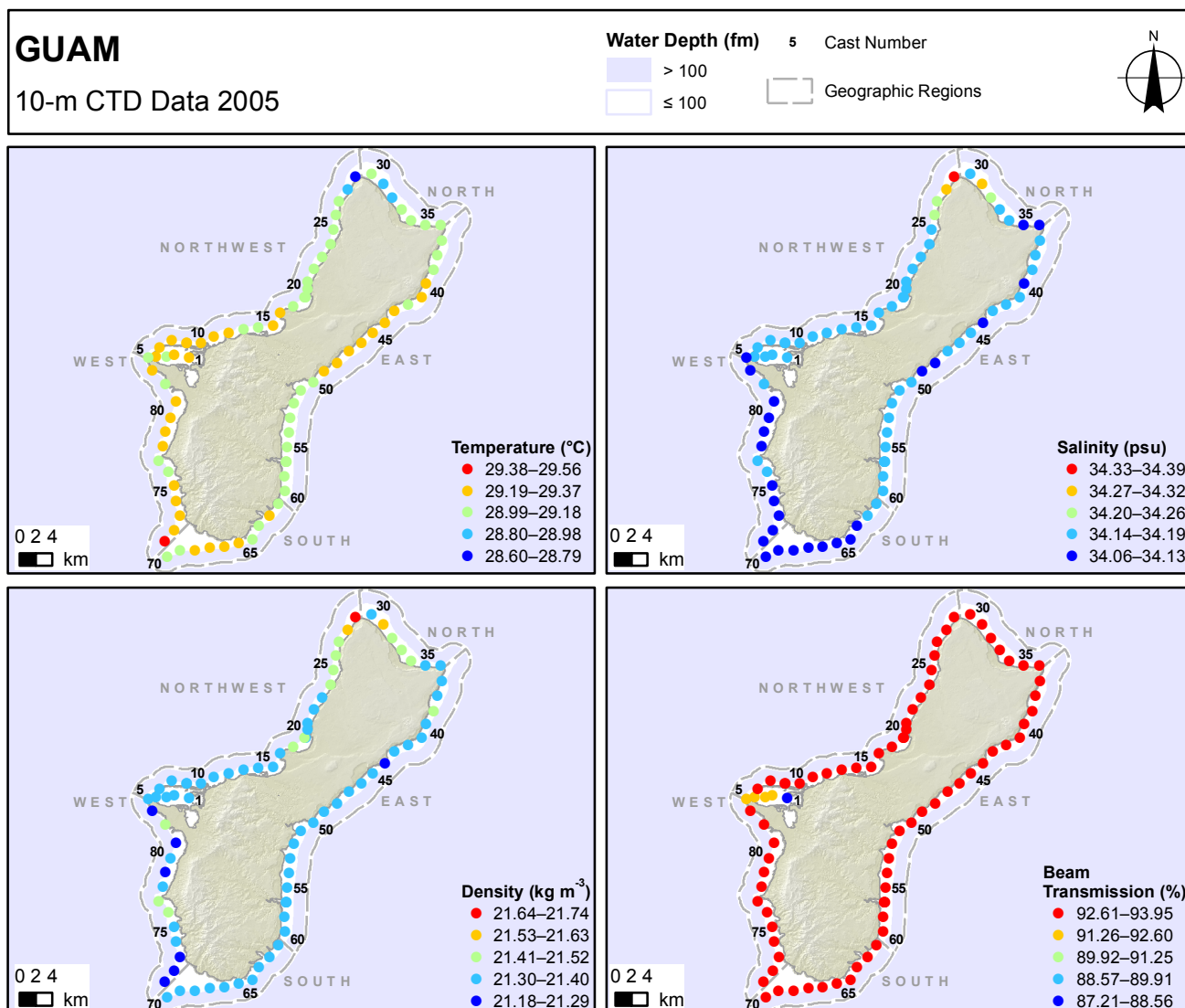

Figure 4.4.1a. Values of (*top left*) water temperature, (*top right*) salinity, and (*bottom left*) density at a 10-m depth from shallow-water CTD casts at Guam on September 22–25 during MARAMP 2003.

Figure 4.4.1b. Shallow-water CTD cast profiles to a 30-m depth at Guam on September 22–25 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–29 in a clockwise direction around Guam. For cast locations and numbers around this island in 2003, see Figure 4.4.1a.


2005 Spatial Surveys

Figure 4.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Guam on October 3–8 during MARAMP 2005.

During MARAMP 2005, 83 shallow-water CTD casts were conducted in nearshore waters around Guam over the period of October 3–8. Temperature, salinity, density, and beam transmission values from these casts varied both spatially and vertically (Figs. 4.4.1c and d). Spatial comparisons of water properties at a depth of 10 m suggest broad ranges around this island: temperature differences as large as 0.96°C with warm water in the west region (cast 71) off Cocos Island and cool water in the northwest region (cast 29) near Ritidian Point (Fig. 4.4.1c). Vertical comparisons of CTD profiles (Fig. 4.4.1d) reveal water properties with broad ranges in temperature (1.6°C), salinity (0.9 psu), density (1.1 kg m^{-3}), and beam transmission (23.6%) values. At the northwest corner of this island around Ritidian Point (cast 29), an intrusion of waters was recorded with cool temperatures of ~ 28.4°C, high salinities of ~ 34.4 psu, and high densities of ~ 21.8 kg m^{-3}, relative to other cast locations around Guam. A series of weaker, cold-water intrusions, similar in both depth (20–30 m) and magnitude to the one in the northwest, were documented around the remainder of Guam (casts 51–52, 59–60, 77–78, and 82). These features were likely formed by the same physical forcing mechanism that resulted in the upwelling of deep water to the near surface. A high temperature of ~ 29.9°C, low salinity of ~ 34 psu, and low density of ~ 21 kg m^{-3} were recorded for surface waters in the west region (cast 71). This warm area probably is associated with surface heating, since it is sheltered from easterly winds by the mountains in southern Guam. Beam transmission values were lowest in Apra Harbor with 70.4% but varied little around the rest of island with 92%–94%.
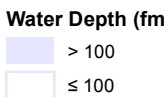
Water samples were collected in concert with shallow-water CTD casts at select locations around Guam in 2005 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.25–1.09 µg L^{-1}; total nitrogen (TN), 0.04–0.40 µM; nitrate (NO$_3^-$), 0.03–0.34 µM; nitrite (NO$_2^-$), 0.02–0.07 µM; phosphate (PO$_4^{3-}$), 0.00–0.03 µM; and silicate [Si(OH)$_4$], 0.20–0.98 µM. Minimum phosphate values (0.00) were below measureable levels. Based on data from 8 sample locations, nearly all parameters were lowest in the south region and the southernmost area in the east region (Fig. 4.4.1e). Compared to conditions around the rest of Guam, Chl-*a*, phosphate, and silicate concentrations were all high inside heavily industrialized Apra Harbor, which is in the southern end of the northwest region. Farther north in the same region, total nitrogen, nitrate, and nitrite values were all highest at Tumon Bay. Elevated nutrient and Chl-*a* levels within Apra Harbor are likely a result of high residence times within this anchorage and potentially an outcome of high runoff. Also, lower concentrations of nitrogen and elevated levels of Chl-*a* within this harbor, relative to other locations around Guam, could indicate terrestrial runoff is enhancing biological productivity there.
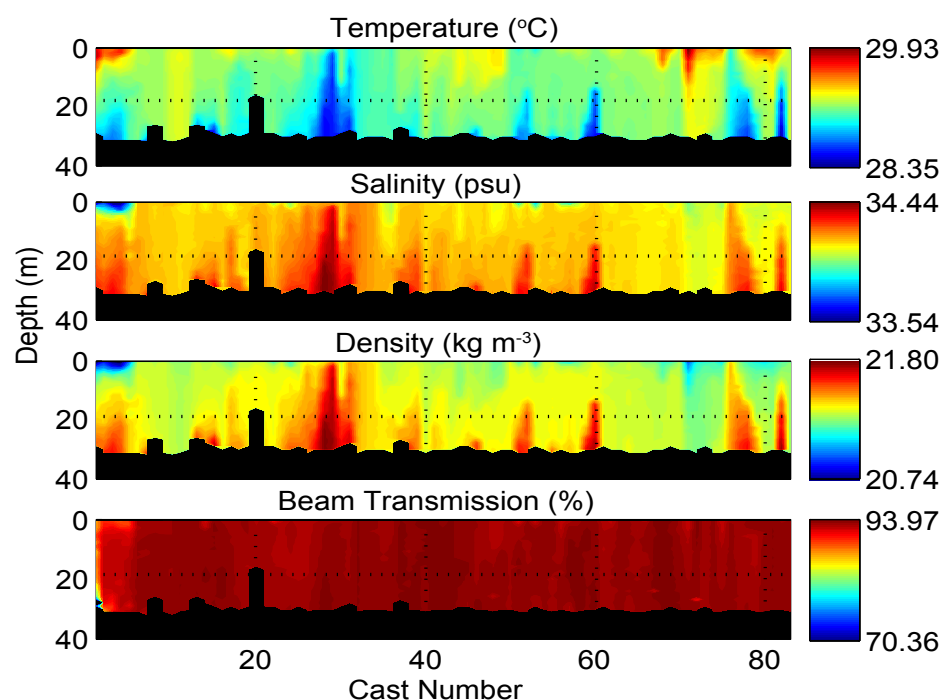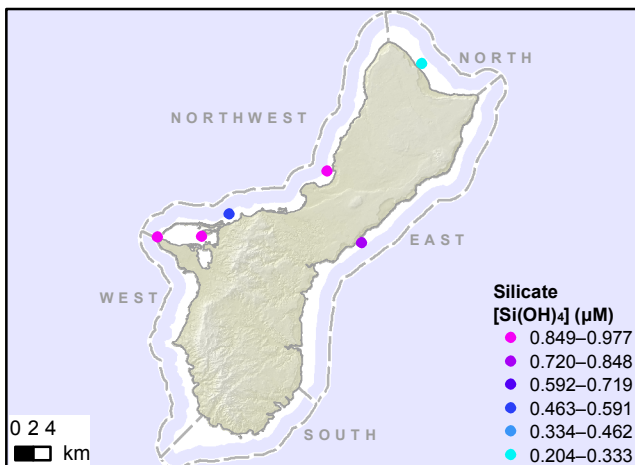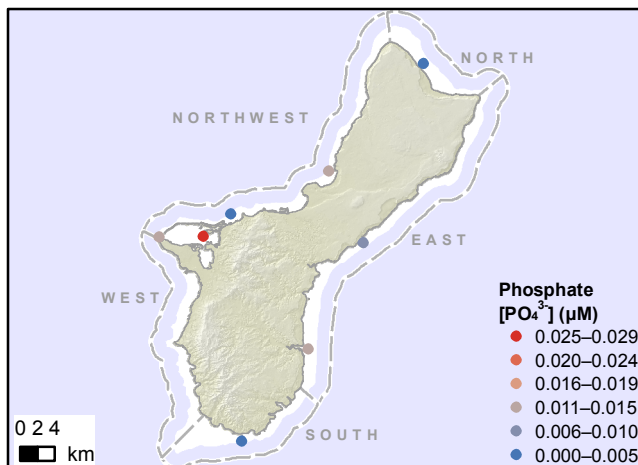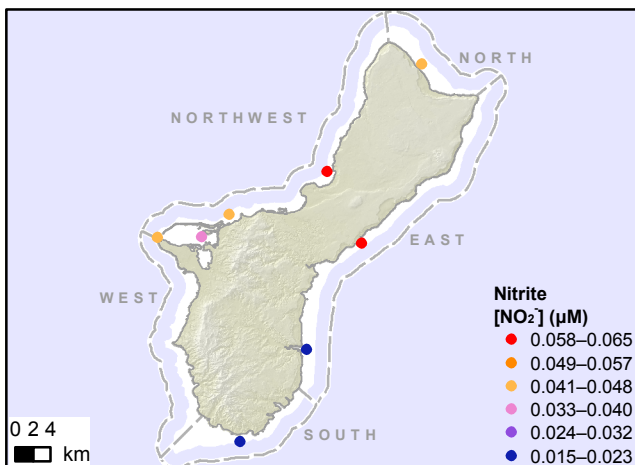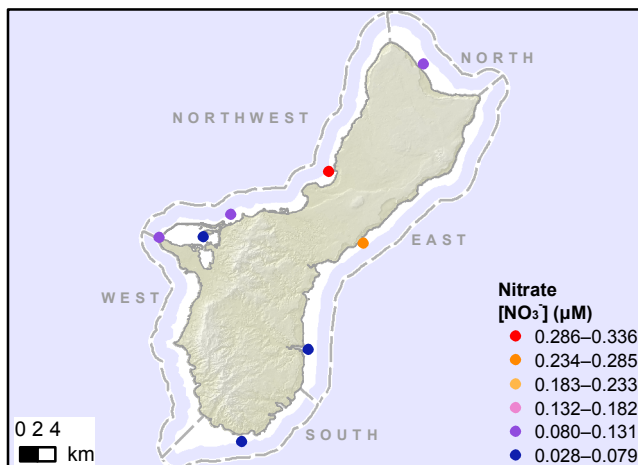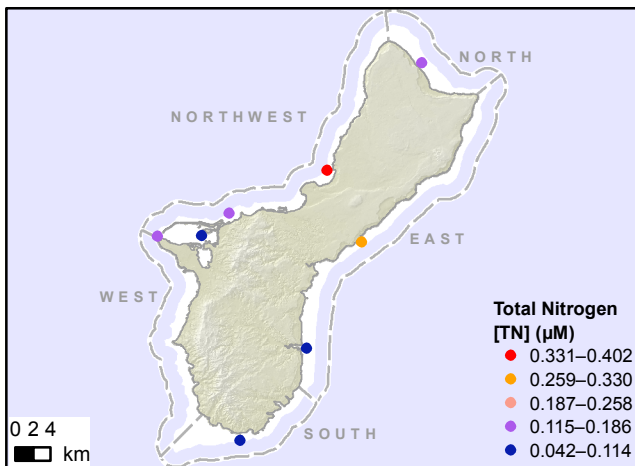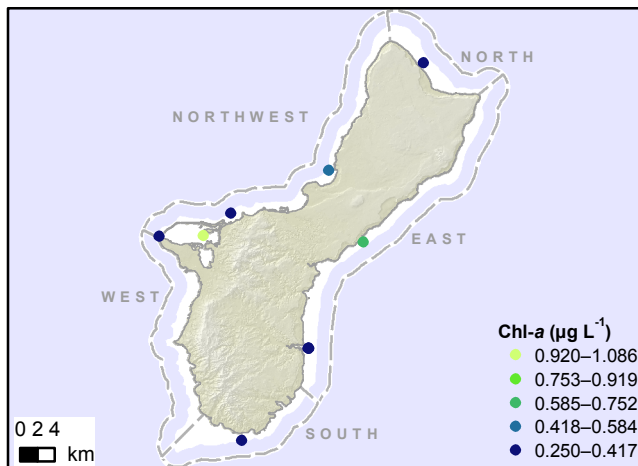

Figure 4.4.1d. Shallow-water CTD cast profiles to a 30-m depth around Guam on October 3–8 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in the graph above, correspond to cast locations that are numbered sequentially 1–83 in a clockwise direction around Guam. For cast locations and numbers around this island in 2005, see Figure 4.4.1c.
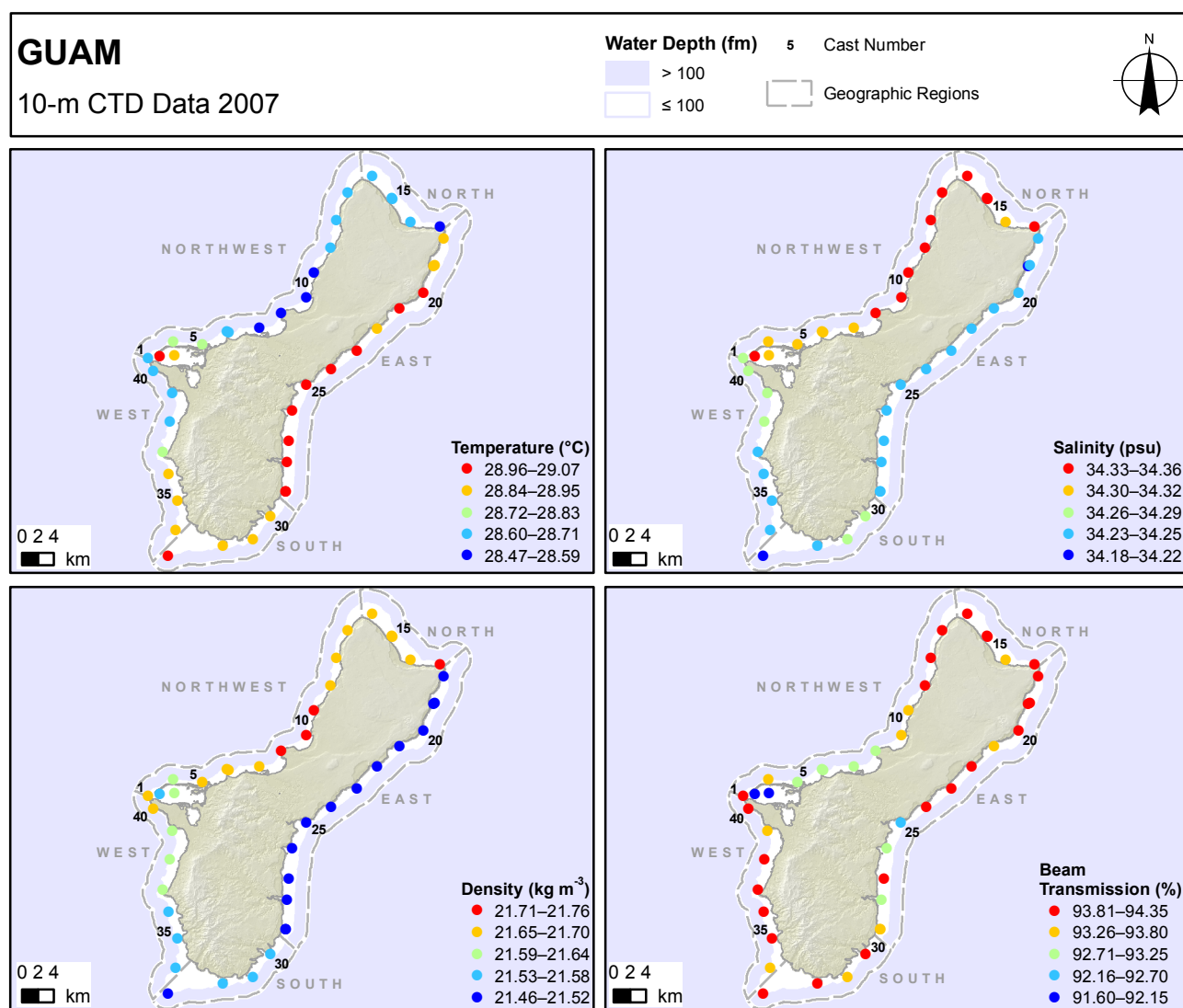
GUAM

10-m Nutrient Data 2005

Water Depth (fm)

> 100

≤ 100

Geographic Regions

N

Chl-*a* (µg L⁻¹)

$Chl\text{-}a \ (\mu g \ L^{-1})$
- 0.920–1.086
- 0.753–0.919
- 0.585–0.752
- 0.418–0.584
- 0.250–0.417

Total Nitrogen
[TN] (µM)
- 0.331–0.402
- 0.259–0.330
- 0.187–0.258
- 0.115–0.186
- 0.042–0.114

Nitrate
[NO₃⁻] (µM)
- 0.286–0.336
- 0.234–0.285
- 0.183–0.233
- 0.132–0.182
- 0.080–0.131
- 0.028–0.079

Nitrite
[NO₂⁻] (µM)
- 0.058–0.065
- 0.049–0.057
- 0.041–0.048
- 0.033–0.040
- 0.024–0.032
- 0.015–0.023

Phosphate
[PO₄³⁻] (µM)
- 0.025–0.029
- 0.020–0.024
- 0.016–0.019
- 0.011–0.015
- 0.006–0.010
- 0.000–0.005

Silicate
[Si(OH)₄] (µM)
- 0.849–0.977
- 0.720–0.848
- 0.592–0.719
- 0.463–0.591
- 0.334–0.462
- 0.204–0.333

Figure 4.4.1e. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected around Guam on October 3–8 during MARAMP 2005.

2007 Spatial Surveys

During MARAMP 2007, shallow-water CTD casts were conducted in nearshore waters around Guam over the period of May 11–15. Temperature, salinity, density, and beam transmission values from 40 of these casts varied both spatially and vertically (Figs. 4.4.1f and g). Spatial comparisons of water properties at a depth of 10 m suggest moderate ranges around this island with temperature differences as large as 0.6°C (Fig. 4.4.1f). The northern part of the west region near Agat Bay and the northwest and north regions (casts 38–17), compared to other cast locations around Guam, had cool temperatures of ~ 28.47°C, high salinities of ~ 34.36 psu, and high densities of ~ 21.76 kg m^{-3}. In the east and south regions of Guam from Pati Point to Cocos Island (casts 18–34), relatively warm temperatures of ~ 29.07°C, low salinities of ~ 34.18 psu, and low densities of ~ 21.46 kg m^{-3} were recorded. Vertical comparisons of CTD profiles (Fig. 4.4.1g) reveal water properties with broad ranges in temperature (1.3°C), density (0.7 kg m^{-3}), and beam transmission (6.1%) values and a moderate range in salinity (0.3 psu) values. Strong gradients in water properties were documented near Pati Point, the northeastern tip of this island (cast 17). Additionally, near Togcha Bay in the east region, an intrusion of cold water with a temperature of 27.9°C was recorded below the area of surface waters with the warmest temperature of 29.2°C (cast 27). Beam transmission around Guam showed a weak positive correlation with temperature and varied broadly by ~ 6%—except in Apra Harbor, where beam transmission of 88.3% was the lowest value around this island.

Figure 4.4.1f. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Guam on May 11–15 during MARAMP 2007.

Water samples were collected in concert with shallow-water CTD casts at 13 select locations around Guam in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: Chl-*a*, 0.01–0.27 µg L^{-1}; total nitrogen (TN), 0.01–0.23 µM; nitrate (NO$_3^-$), 0.00–0.22 µM; nitrite (NO$_2^-$), 0.01–0.02 µM; phosphate (PO$_4^{3-}$), 0.02–0.12 µM; and silicate [Si(OH)$_4$], 0.75–1.68 µM. Minimum nitrate values (0.00) were below measureable levels. Based on data from these samples around Guam, the greatest Chl-*a* value was recorded in the northwest region, where nitrite was also at peak concentration. In the west region, nearly all parameters were at their lowest concentrations, with the exception of nitrite, which was in the middle of the observed range of values for Guam. Elevated levels of Chl-*a*, silicate, and nitrite concentrations were found in Apra Harbor. Nitrite concentrations were also elevated just outside this harbor, but all other measured parameters were recorded in the middle to low end of the observed ranges for Guam.

Figure 4.4.1g. Shallow-water CTD cast profiles to a 30-m depth around Guam on May 11–15 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–40 in a clockwise direction around Guam. For cast locations and numbers around this island in 2003, see Figure 4.4.1f.
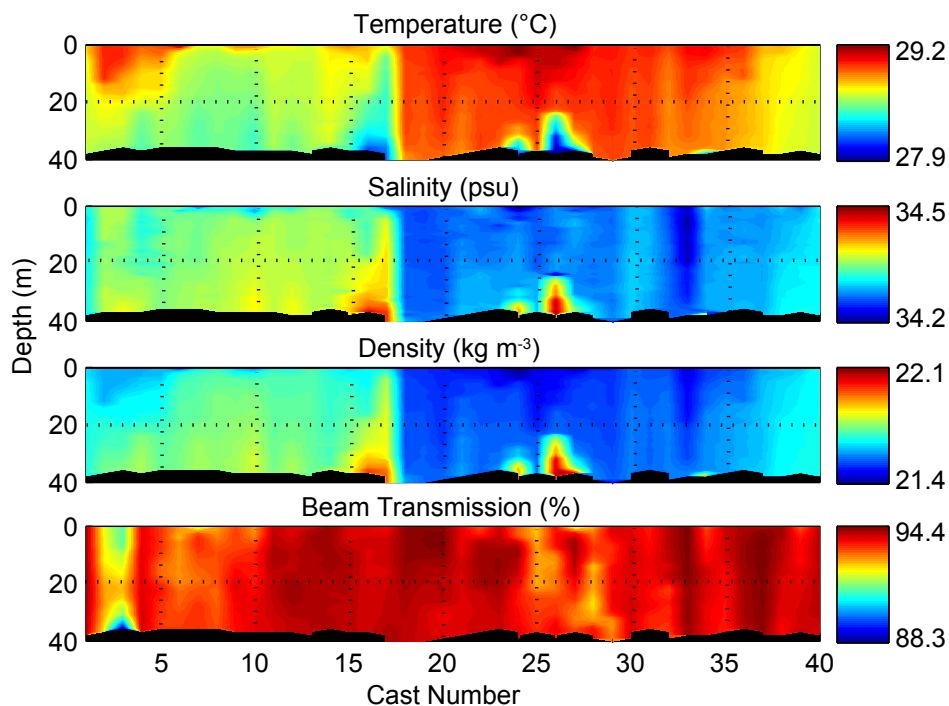
GUAM

10-m Nutrient Data 2007

Water Depth (fm)
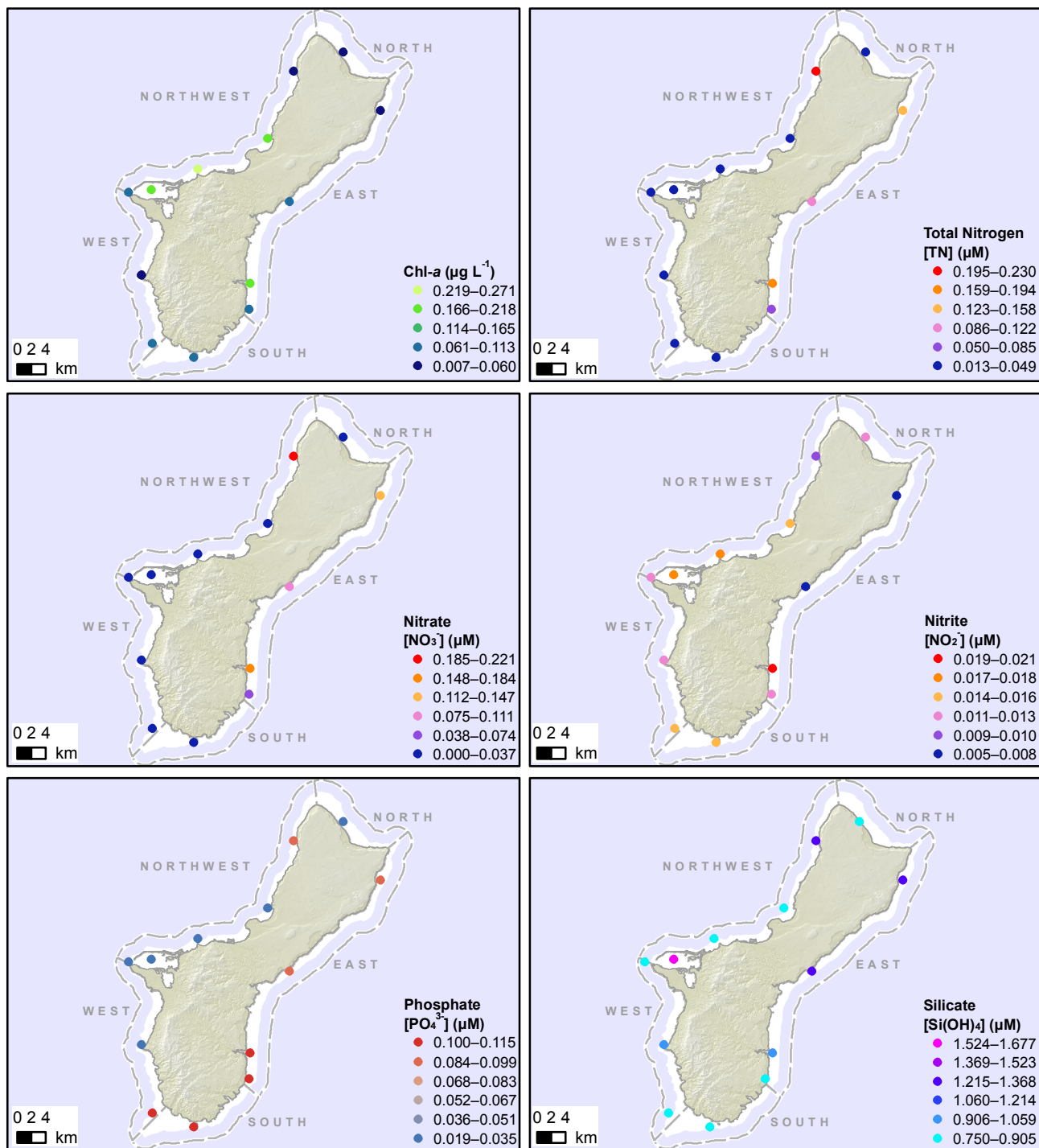> 100
≤ 100

Geographic Regions

N

Figure 4.4.1h. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected around Guam on May 11–15 during MARAMP 2007.

Temporal Comparison

Temperature ranges around Guam were > 1°C from all shallow-water CTD casts conducted during MARAMP 2003, 2005, and 2007, although the maximum and minimum temperatures recorded during each survey period decreased with each subsequent survey year. Intrusions of cold water originating from 30 m below the ocean surface were recorded during each survey period; however, they were most prevalent during MARAMP 2005. Strong east–west gradients in water properties were documented during each survey year. During MARAMP 2003 and 2005, waters in the east region were cooler than waters in the west and northwest regions; these differences were likely a result of vertical mixing that was induced by trade winds and mixed cooler subsurface waters into the upper 30 m of the water column. Data from MARAMP 2007, however, shows the opposite pattern: temperatures were warmer on the east side than on the west side. Beam transmission was lowest in Apra Harbor during each survey period. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in September and October. This change was made to avoid the typhoon season and reduce the probability of weather disruptions. Wind and wave conditions are generally higher during the wet season (July–December) than during the rest of the year, with stronger trade winds prominent on the east side of Guam. Higher winds and waves likely caused more mixing during MARAMP 2003 and 2005, and calmer weather potentially allowed for increased stratification in 2007. Further investigation will help make these particular results and patterns more apparent.

The number of locations where water samples were collected in 2007 was almost double the number in 2005. Some differences in water conditions between MARAMP 2005 and 2007 were observed, although similarities, such as water quality in Apra Harbor, existed. Using the maximum value bins measured for total nitrogen and phosphate, the calculated nitrogen-to-phosphorus (N:P) or Redfield ratio was 2:1 for samples from MARAMP 2007 (Redfield 1958). A low ratio of < 16:1 suggests a potential nitrogen limitation, while a high ratio of > 16:1 suggests a limitation in the primary production of phytoplankton. The N:P ratio for MARAMP 2005 for the same constituents was 15:1, closer to the expected Redfield ratio of 16:1. To elucidate the forcing factors present to produce an N:P ratio of 2:1 in 2007 would require further studies. Still, it is worth noting that highly variable N:P ratios around Guam have been recorded. Maximum Chl-*a* and total nitrogen were greater in 2007 than in 2005, while phosphate and silicate maximums were lower. These trends could be linked to seasonal weather patterns, terrigenous runoff, or nutrient limitation.

4.4.2   Time-series Observations

Figure 4.4.2a. Locations, depths, and types of oceanographic instrument moorings deployed at Guam during MARAMP 2003, 2005, and 2007. Three types of instruments were moored at Guam: ecological acoustic recorder (EAR), sea-surface temperature (SST) buoy, and subsurface temperature recorder (STR).
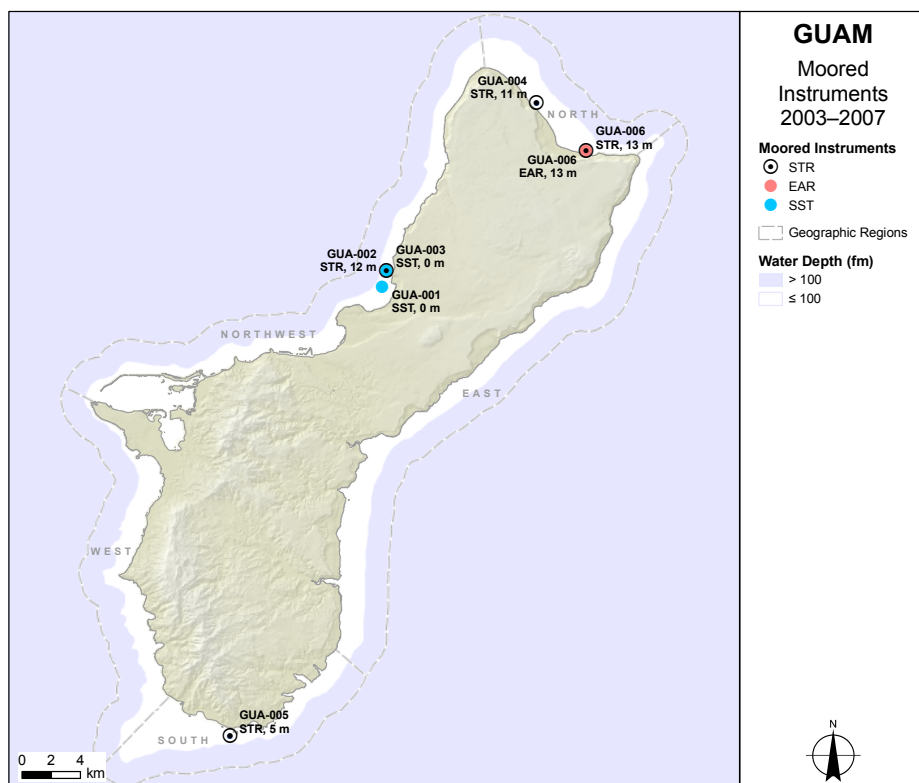
Between 2003 and 2007, a suite of moored instruments was deployed at Guam to collect time-series observations of key oceanographic parameters. The locations, depths, time frames, and other details about these deployments are provided in Figures 4.4.2a and b.
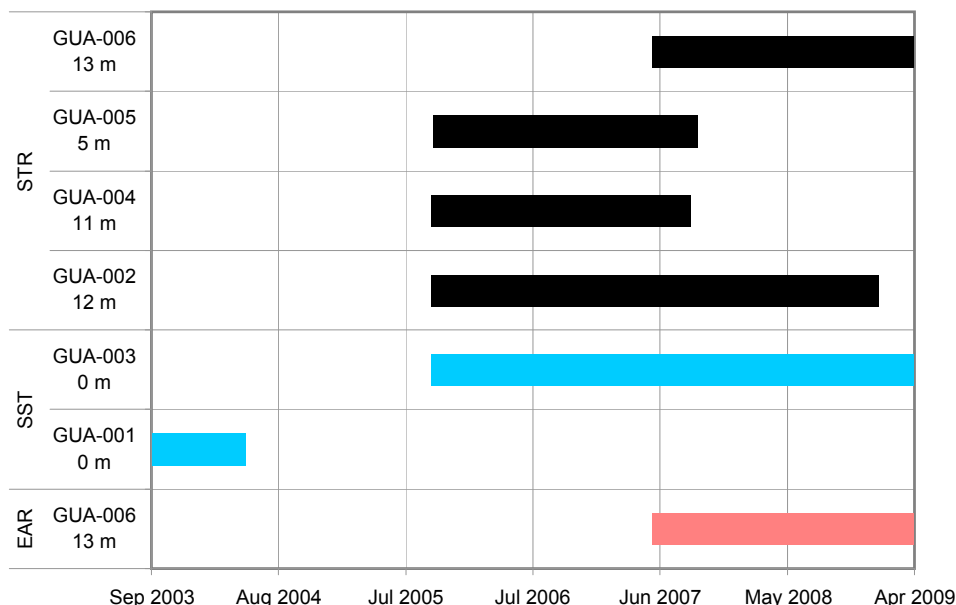
Figure 4.4.2b. Deployment time-lines and depths of oceanographic instruments moored at Guam during the period from September 2003 to April 2009. A solid bar indicates the period for which data were collected by a single instrument or a series of them deployed and retrieved at a mooring site. For more information about deployments and retrievals, see Table 4.2b in Section 4.2: "Survey Effort."

Satellite-derived (Pathfinder) sea-surface temperature (SST) and in situ temperature observations around Guam reveal that the seasonal maxima for water temperatures around Guam are typically reached in late August or September; the monthly maximum climatological mean from Pathfinder SST was 29.5°C (Fig. 4.4.2c[a]). Winter minima occured in February with a monthly minimum climatological mean of 27.1°C. Data from the SST buoys near Tumon Bay and 3 subsurface temperature recorders (STRs) show that water temperatures around Guam in August–September 2006 rose above the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean (Figs. 4.4.2c[a] and d). Still, given the relatively short duration and small magnitude of this period of elevated temperature, widespread mass coral bleaching likely did not occur. It's important to note that satellite-derived SST represents the upper few millimeters of oceanographic temperatures within the region of an island, as opposed to site- or reef-specific temperatures.
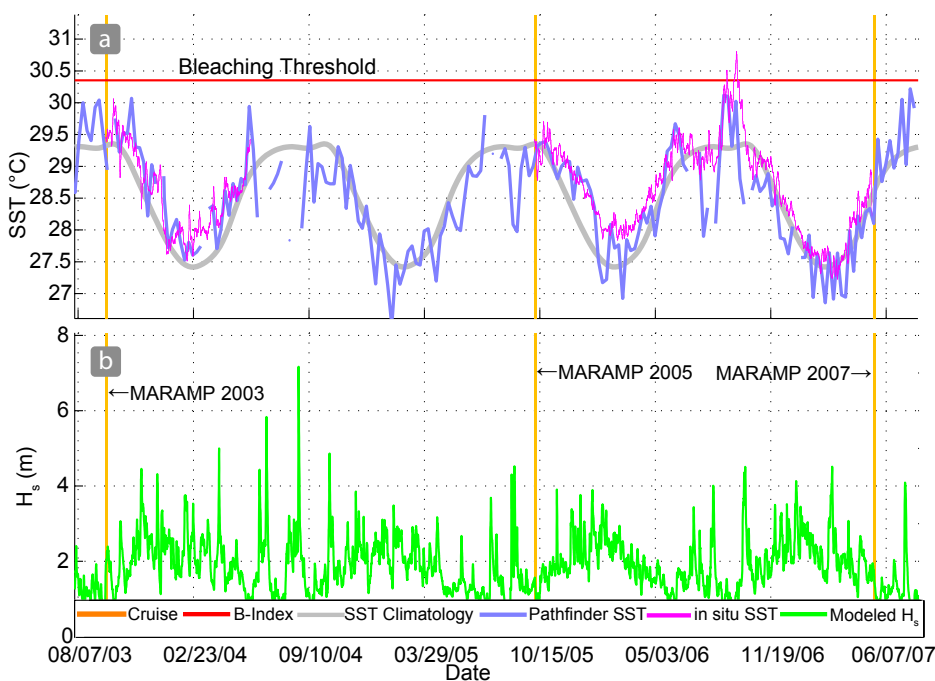

Figure 4.4.2c. Time-series observations of (*a*) SST and (*b*) wave height around Guam for the period between August 2003 and June 2007. Remotely sensed data (SST climatology and weekly Pathfinder-derived SST) and modeled significant wave height (H_s) derived from Wave Watch III are shown with CRED in situ temperature data from SST buoys (see Figure 4.4.2a for buoy locations). The 2 high points in the modeled wave height in the summer of 2004 show the occurrences of Typhoons Tingting and Chaba. The horizontal red and vertical orange bars represent the satellite-derived bleaching threshold and the MARAMP research cruise dates, respectively.

Periods of elevated mean wave heights of 3–4 m were usually more frequent during winter (Fig. 4.4.2c[b]). The largest episodic events of wave heights > 4 m, however, tended to happen during periods of warm temperatures. Warm temperatures typically occur during the period of August–December, when wave heights of > 4 m are generally associated with typhoons. This pattern was especially noticeable during the summer of 2004 with the passages of Typhoons Tingting and Chaba.

Three subsurface temperature recorders (STRs) were deployed at depths of 5, 11, and 12 m around Guam beginning in October 2005. Data from all of these STRs show seasonal temperature variability of 2°C–3°C (Fig. 4.4.2d). Water temperatures reached ~ 30.5°C during the months of June–October and fell to a low of ~ 27°C during the months of January–May. Temperature at these 3 locations exceeded the coral bleaching threshold for the region in September 2006, with the temperature at the shallowest sensor reaching almost 1°C higher than the bleaching threshold of 30°C. Diurnal temperature fluctuations were ~ 0.5°C for this shallowest sensor and ~ 0.3°C for the 2 deeper sensors. Solar heating and cooling caused the greater diurnal temperature fluctuation that was recorded at the shallowest deployment.

Figure 4.4.2d. Time-series observations of temperature over the period between October 2005 and May 2007 collected from 3 STR mooring sites at different locations and depths around Guam (see Figure 4.4.2a for mooring locations). The red lines indicate the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.
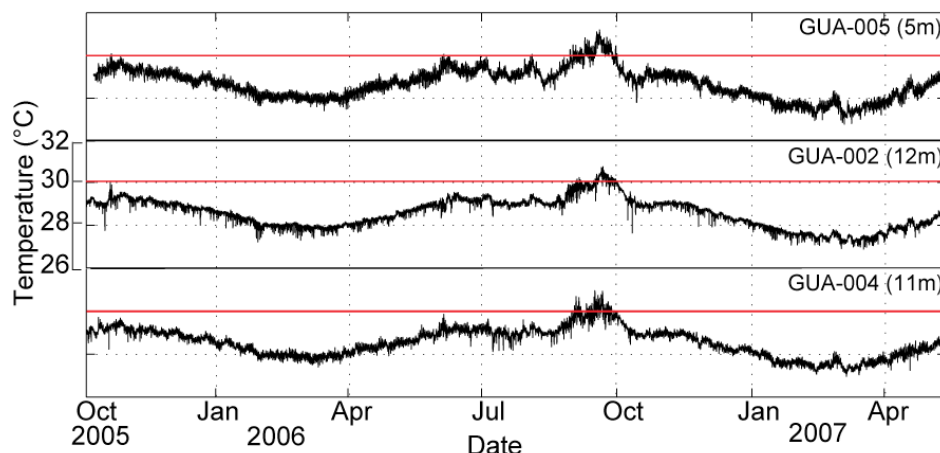

Precipitation at Guam from 2001 to mid-2008 was highly seasonal with the greatest rainfall occurring in the months of August–September and the lowest occurring in the months of February–April (Fig. 4.4.2e). MARAMP 2003 and 2005 cruises were conducted in September and October, which are months characterized by seasonally high precipitation. In contrast, MARAMP 2007 was conducted in May when rainfall was seasonally low.

Figure 4.4.2e. Average monthly rainfall (m) from the Guam International Airport from January 2001 to July 2008. The cyan line indicates precipitation climatology (1958–2008), and the vertical red bars indicate MARAMP cruise periods. Source: National Weather Service, Honolulu (http://www.prh.noaa.gov/hnl/).
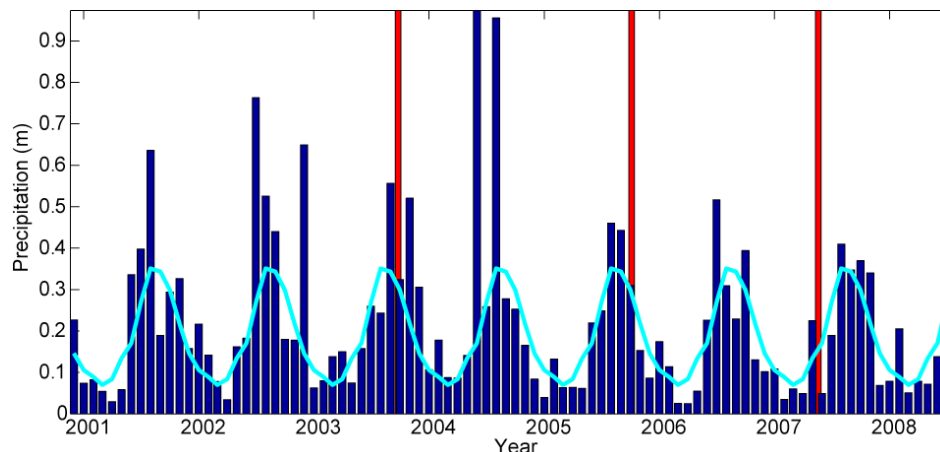
4.4.3 Wave Watch III Climatology

Seasonal wave climatology for Guam (Fig. 4.4.3a) was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: "Methods and Operational Background," Section 2.3.7: "Satellite Remote Sensing and Ocean Modeling"). In terms of consistency, the wave regime during this period was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east (~ 75°). Superimposed with these short-period swells were large (> 4 m), long-period (12–16 s) wave events principally from the southeast (~ 110°), but they could originate from a broad directional source (90°–180°). These large, episodic waves were generated primarily by typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate wave heights (2.5–3.5 m) occurred from the west-southwest (~ 250°) and probably were associated with episodic storms. Similar to the regime during typhoon season, the wave climate during the period of February–June (outside the typhoon season) also was characterized by frequent (> 30 d per season), short-period (~ 8 s) trade wind swells with relatively small wave heights (~ 2 m) originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with slightly larger wave heights (~ 3 m) also occurred during this period and originated from the southwest (~ 240°).
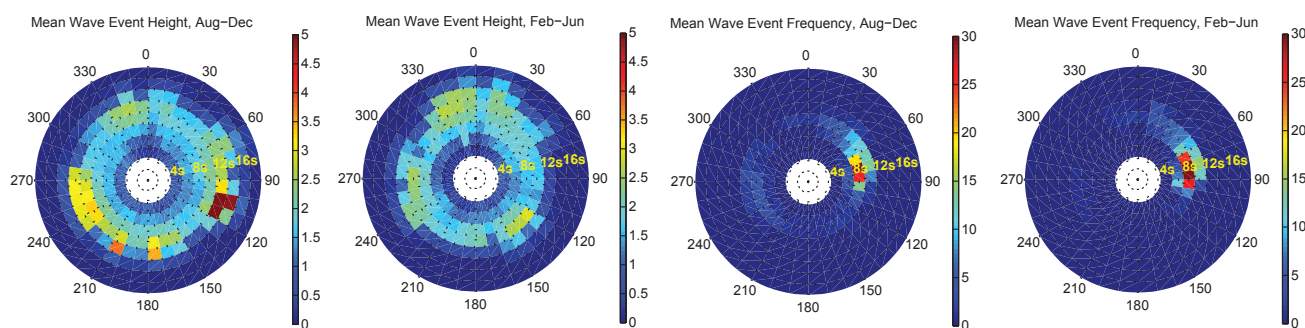
Figure 4.4.3a. NOAA Wave Watch III directional wave climatology for Guam from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box (1° × 1°) centered on Guam (13° N, 145° E). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 of the 150 days of that season.

4.4.4 Bioacoustic Observations

In the north region just west of Pati Point, an ecological acoustic recorder (EAR) unit was deployed on May 14, 2007. Programmed to record the ambient sound field at a sample rate of 40 kHz for 30 s every 10 min, this EAR unit was also programmed to detect and record high-amplitude noise events, such as the engine sounds of passing vessels. Unfortunately, this unit was flooded and no data are available to report. A replacement EAR was deployed in May 2009.

4.5 Corals and Coral Disease

4.5.1 Coral Surveys

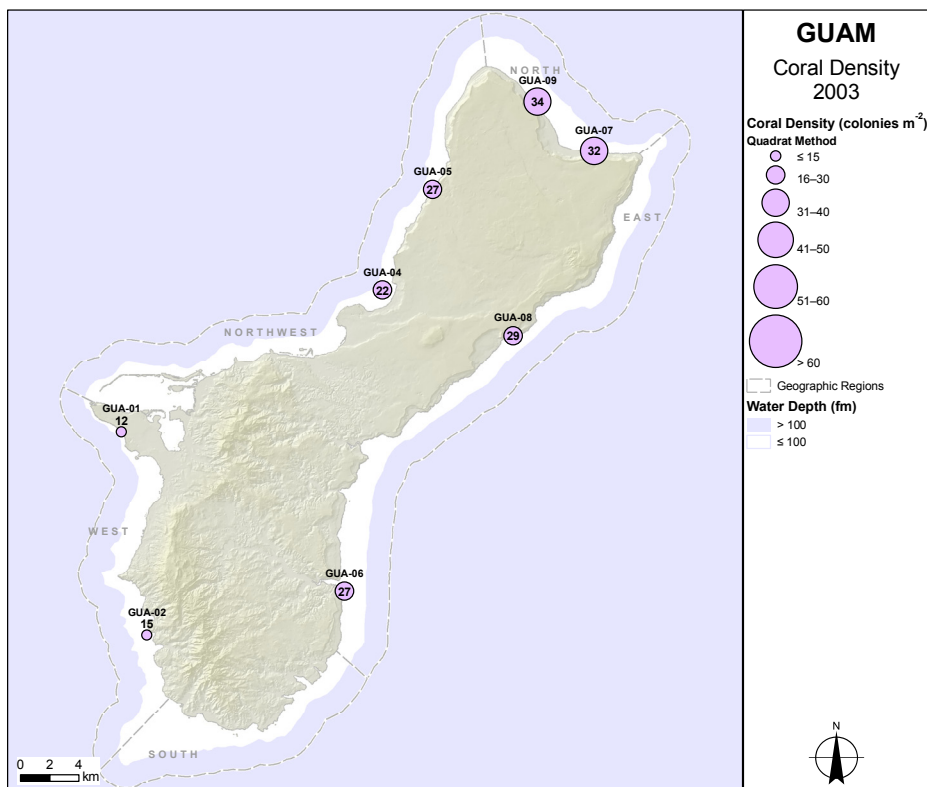#### *Coral Cover and Colony Density*

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Guam was 19% (SE 1). Coral cover was lowest in the west region (Fig. 4.5.1a), with a mean of 7% for 39 survey segments, and was variable in all other regions. The highest cover was observed in the north region with a mean of 25% for 20 segments and in the east region with a mean of 25% for 67 segments. Localized areas of high coral cover were observed on the forereef off Jalaihai Point, near the boundary between the east and south regions, over 3 segments with a mean of 42% and along Catalina Point, in the northern portion of the east region, for 7 segments with a mean of 45% (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort").

Figure 4.5.1a. Cover (%) observations of live hard corals from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m^2).
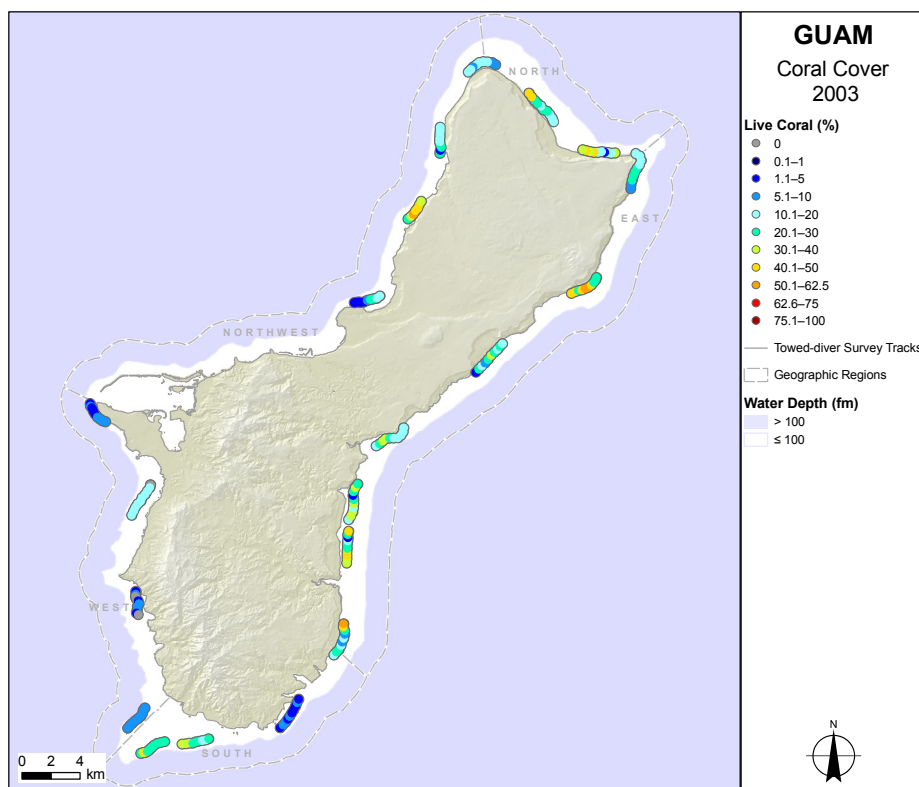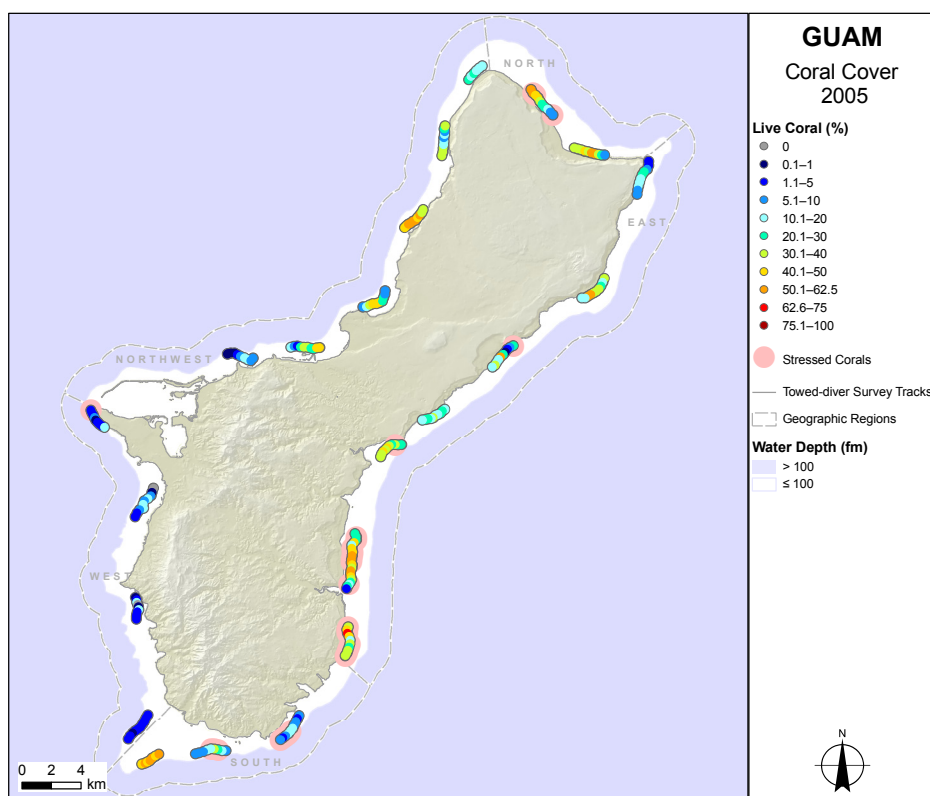

During MARAMP 2003, 8 REA benthic surveys using the quadrat method on forereef habitats around Guam documented 718 coral colonies within a total survey area of 30 m^2. Site-specific colony density ranged from 11.7 to 33.9 colonies m^{-2} with an overall sample mean of 24.6 colonies m^{-2} (SE 2.8) around Guam. The highest colony density was recorded at GUA-09 near Jinapsan Point, and the lowest colony density was observed in the west region at GUA-01 near Orote Peninsula and GUA-02 in Cetti Bay (Fig. 4.5.1b).

Figure 4.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. Values are provided within or above each symbol. The quadrat method was used in 2003 to assess coral-colony density.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Guam was 23% (SE 1.2). Similar to surveys in 2003, coral cover was lowest within the west region (Fig. 4.5.1c), with a mean of 5% over 39 segments. Coral cover was variable in all other regions with the highest mean coral cover in the north region, for 20 segments with a mean of 34%, and east region, over 80 segments with a mean of 29%. Localized areas of high coral cover were recorded south of Cocos Island for 7 segments with a mean of 51%, off of Haputo Point in the northwest region over 10 segments with a mean of 49%, off of Jalaihai Point for 4 segments with a mean of 48%, and along Catalina Point over 5 segments with a mean of 44%.

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, 5% (SE 0.6) of coral cover observed on forereef habitats around Guam appeared stressed in 2005. Stressed-coral cover was highest in the south and east regions (Fig. 4.5.1c) with means of 9% and 7% and lowest in the west region with a mean of 1%. Some observations of stressed corals appeared related to crown-of-thorns seastar (*Acanthaster planci*) abundance, which was highest between Togcha and Talofofo Bays in the east region. Divers recorded more than 100 crown-of-thorns seastars (COTS) during a 5-min segment just south of Togcha Bay. For more about COTS around Guam, see Section 4.7.1: "Benthic Macroinvertebrate Surveys."
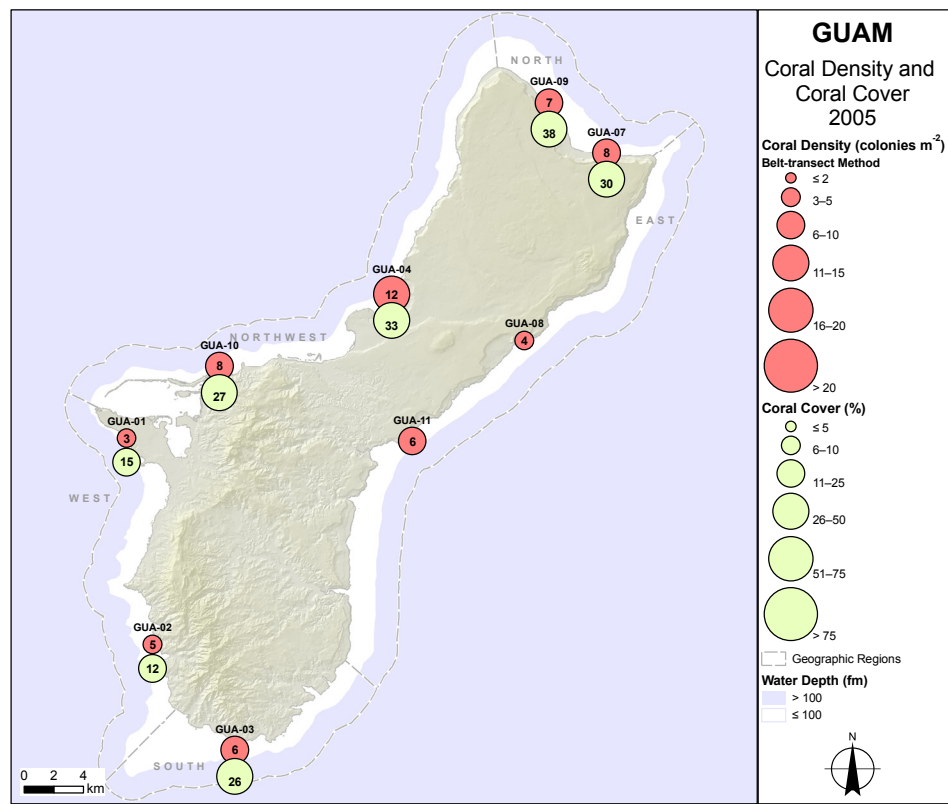

Figure 4.5.1c. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m^2). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005.

During MARAMP 2005, 7 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats around Guam. Site-specific estimates of live-hard-coral cover from these surveys ranged from 11.8% to 38.2% (Fig. 4.5.1d) with an overall sample mean of 26.1% (SE 3.6). Live coral cover was not assessed at GUA-08 and GUA-11 in the east region because of personnel limitations. In the north region at GUA-09 and GUA-07 and in the northwest region at GUA-04, levels of live coral cover were found at the high end of this range: 38.2%, 30.4%, and 33.3%. The lowest coral cover of 11.8% was recorded at GUA-02 in Cetti Bay.

During MARAMP 2005, 9 REA benthic surveys using the belt-transect method on forereef habitats around Guam documented 5018 coral colonies within a total survey area of 750 m^2. Site-specific colony density ranged from 3.1 to 12.3 colonies m^{-2} with an overall sample mean of 6.5 colonies m^{-2} (SE 0.9) around Guam. The highest colony density was recorded at GUA-04 in Tumon Bay (Fig. 4.5.1d), the site with the second-highest coral cover. Similar to results from 2003 surveys, GUA-01 and GUA-02 in the west region were among the sites with the lowest coral densities of 3.1 and 4.7 colonies m^{-2}; they were also the 2 sites with the lowest coral cover.

Figure 4.5.1d. Cover (%) and colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. Values are provided within each symbol. The belt-transect method was used in 2005 to assess coral-colony density.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats around Guam was 12% (SE 0.8). Again, coral cover was lowest in the west region (Fig. 4.5.1e), with a mean of 4% for 30 segments, and highest in the north region with a mean of 21% over 20 segments. Areas of relatively high, continuous coral cover were observed just west of Pati Point in the north region, over 6 segments with a mean of 35%, and along Catalina Point with a mean of 35% for 10 segments.

Figure 4.5.1e. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m²). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2007.
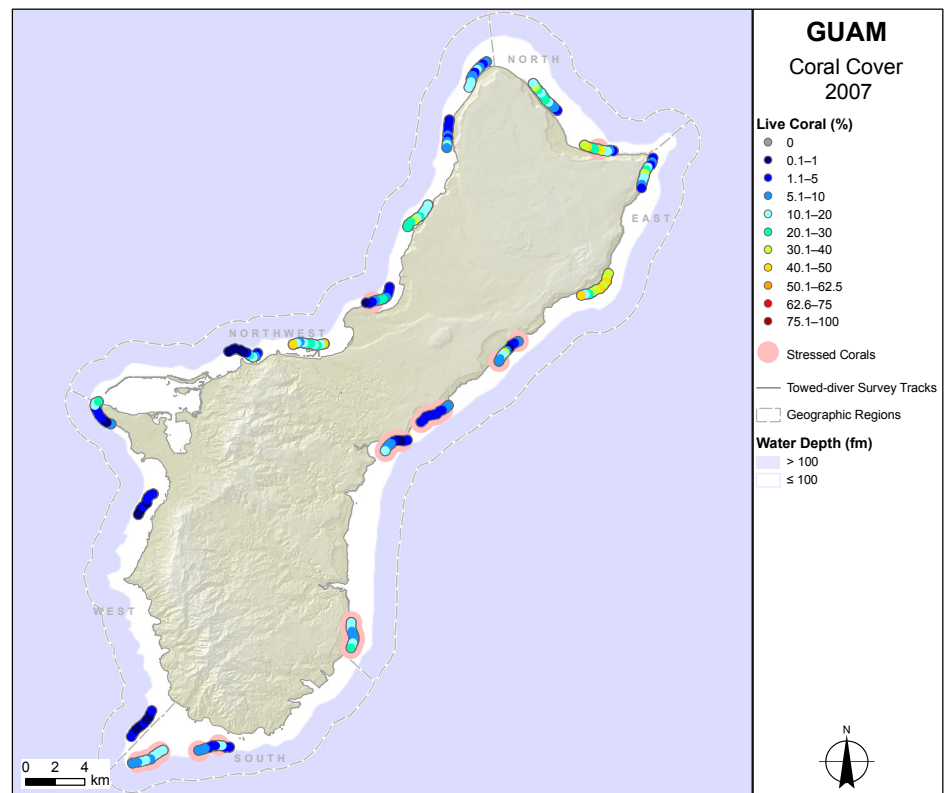
Overall, 5% (SE 0.6) of coral cover observed on forereef habitats around Guam appeared stressed in 2007 (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease). Similar to 2005 findings, stressed-coral cover was highest in the south and east regions (Fig. 4.5.1e). In these 2 regions, where stressed-coral cover was recorded with means of 8% and 10%, divers noted that predation scars and COTS presence were common. The highest overall cover of stressed corals was located south of Talofofo Bay to Jalaihai Point. A localized increase in stressed-coral cover was noted around Fadian Point, where observers recorded abundant COTS and predation scars affecting up to 40% of live corals.

During MARAMP 2007, 10 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats around Guam. Site-specific estimates of live-hard-coral cover from these surveys ranged from 4.9% to 39.2% (Fig. 4.5.1f) with an overall sample mean of 16.2% (SE 3.1). Live coral cover was highest at GUA-08 near Campanaya Point, which had not been assessed for cover of live corals during 2005 surveys. Similar to results from the 2005 surveys, relatively high values of coral cover were found at the 2 sites in the north region, GUA-07 and GUA-09, and the lowest coral cover was recorded at GUA-02 in Cetti Bay in the west region. All REA sites surveyed for coral cover in 2005 showed a decline in 2007.

During MARAMP 2007, 10 REA benthic surveys using the belt-transect method on forereef habitats around Guam documented 3080 coral colonies within a total survey area of 500 m^2. Site-specific colony density ranged from 3.4 to 11.1 colonies m^{-2} with an overall sample mean of 6.2 colonies m^{-2} (SE 0.7) around Guam. The highest colony density was recorded at GUA-10 near Adelup Point in the northwest region (Fig. 4.5.1f). As in the 2003 and 2005 surveys, GUA-02 in Cetti Bay with 3.9 colonies m^{-2} ranked among the sites with the lowest coral densities.
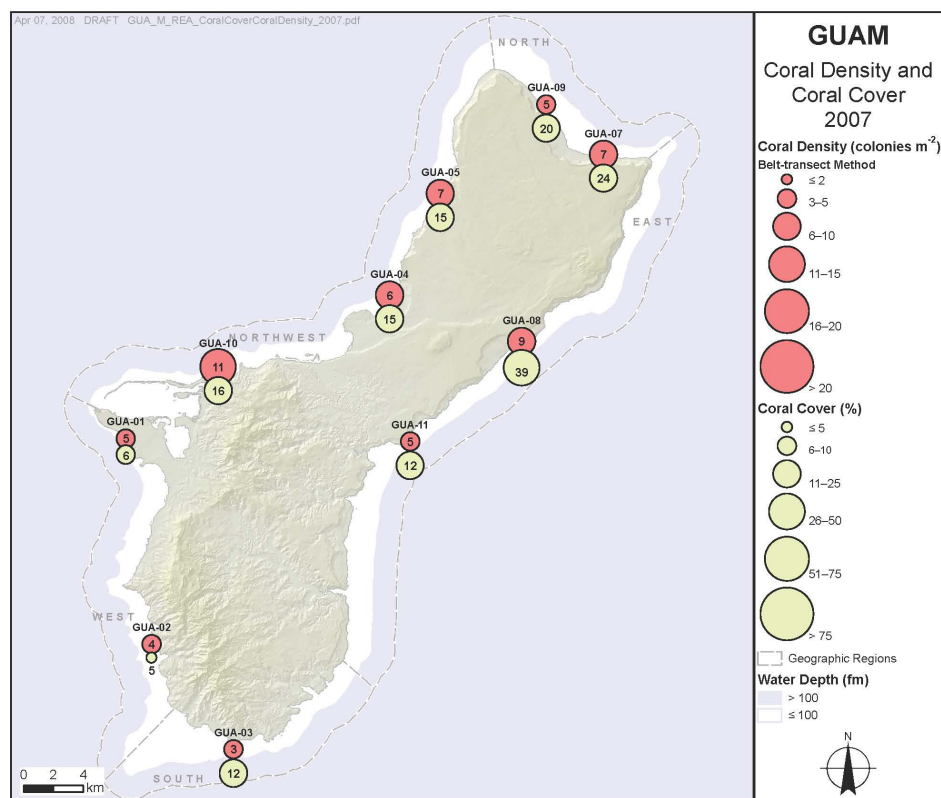
**Figure 4.5.1f.** Cover (%) and colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Values are provided within each symbol. The belt-transect method was used in 2007 to assess coral-colony density.

Islandwide mean cover of live corals estimated from towed-diver surveys of forereef habitats varied between years, rising from 20% (SE 1) in 2003 to 23% (SE 1.2) in 2005 then falling to 12% (SE 0.8) in 2007 (Fig. 4.5.1g). In close agreement with these values, overall mean estimates of coral cover around Guam from site-specific REA surveys decreased from 26.1% (SE 3.6) in 2005 to 16.2% (SE 3.1) in 2007 with coral cover decreasing at all 7 sites surveyed in both 2005 and 2007 (Guam was not surveyed for live coral cover using the line-point-intercept method in 2003). This congruence of data from surveys using 2 separate methods over different spatial scales suggests that this decrease in coral cover was genuine rather than an artifact of environmental heterogeneity, interobserver bias, or variable locations of survey tracks and REA sites between years.
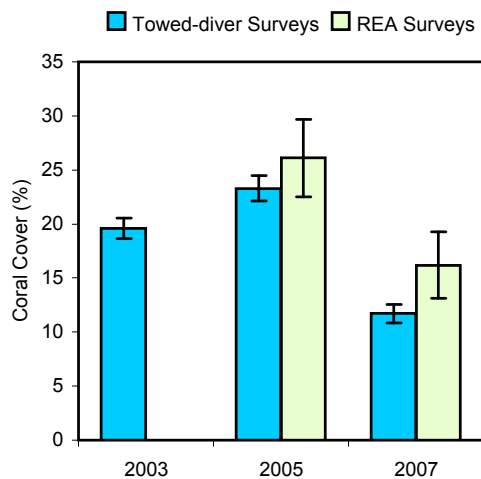
Figure 4.5.1g. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Guam in 2003. Error bars indicate standard error (± 1 SE) of the mean.
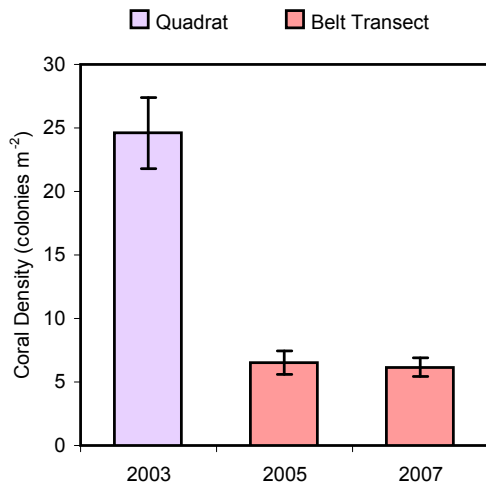
Figure 4.5.1h. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 to measure coral colony density, but the belt-transect method was used in 2005 and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Between MARAMP towed-diver survey efforts, estimates of high coral cover remained consistent in the north and east regions, where coral cover was 23% and 25% in 2003 and 34% and 29% in 2005. In the north region, towed-diver surveys overlapped with GUA-09 and GUA-07, where values of coral cover were among the highest recorded around the island in both years. Localized areas of high coral cover were also noted in the east region: at Catalina Point, where it averaged 45% over 7 segments in 2003, 44% over 5 segments in 2005, and 35% over 10 segments in 2007, and at Jalaihai Point for 3 segments with a mean of 42% in 2003 and for 4 segments with a mean of 49% in 2005. Finally, low values of coral cover were recorded every year in the west region: 7% in 2003, 5% in 2005, and 3% in 2007.

Overall, stressed-coral cover observed on forereef habitats was consistently highest in the south and east regions, where it was recorded at 9% and 7% in 2005 and 9% and 10% in 2007. High values of stressed-coral cover in both years and regions may have resulted from a number of causes, including but not limited to COTS predation, as well as disease and sedimentation, both of which were noted by divers during MARAMP 2005 surveys between Tagachang and Jalaihai Points.

Overall mean coral-colony density from REA benthic surveys of forereef habitats around Guam did not vary substantially between MARAMP 2005 and 2007, when the belt-transect method was used, remaining steady at 6.5 colonies m^{-2} (SE 0.9) and 6.2 colonies m^{-2} (SE 0.7), respectively (Fig. 4.5.1h). Site-specific coral-colony densities appeared substantially higher in 2003, as did the overall mean density for Guam at 24.6 colonies m^{-2} (SE 2.8), than in 2005 and 2007. However, this disparity is likely an artifact of the different method used to assess colony density in 2003 than in 2005 and 2007. The method of placing quadrats used in 2003 was highly biased toward surveying hard-bottom substrate where corals were present, whereas the belt-transect method used in 2005 and 2007 assessed benthos that fell within transect belts regardless of the nature of the substrate.

Coral Generic Richness and Relative Abundance

Eight REA benthic surveys of forereef habitats were conducted using the quadrat method around Guam during MARAMP 2003. At least 29 coral genera were observed around Guam. Generic richness ranged from 7 to 17 with a mean of 12 (SE 1) coral genera per site (Fig. 4.5.1i). The highest generic diversity was seen at GUA-09 near Jinapsan Point in the north region, and the lowest generic diversity was recorded at GUA-01 on the west side of Orote Peninsula.

Porites, *Leptastrea*, *Favia*, *Astreopora*, and *Montipora* were the most numerically abundant genera, contributing 19.8%, 16.8%, 13.5%, 14.2%, and 12.4% of the total number of colonies enumerated around Guam during MARAMP 2003. All other genera individually contributed < 10% of the total number of colonies. *Porites* dominated the coral fauna at GUA-02 in Cetti Bay and GUA-04 in Tumon Bay (Fig. 4.5.1i). *Leptastrea* dominated the coral fauna at GUA-01 in the west region, GUA-05 in the northwest region, and GUA-07 in the north region. *Favia* dominated the coral fauna at GUA-06 and GUA-08 in the east region and GUA-09 in the north region. The values of relative abundance of coral genera at GUA-06 and GUA-08 were highly similar.
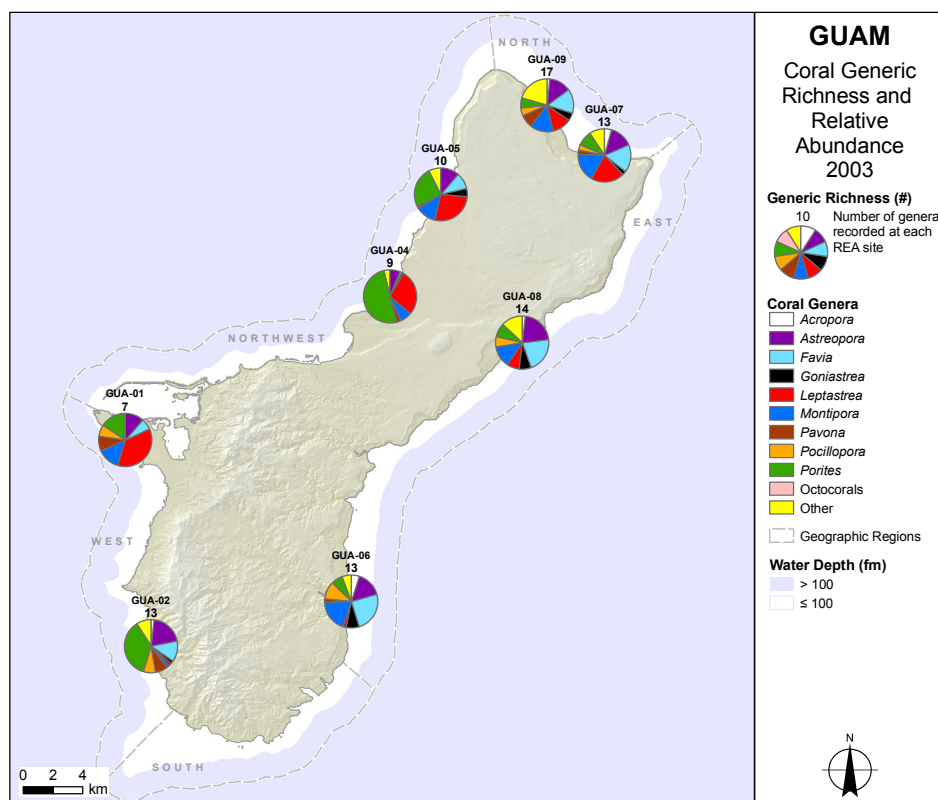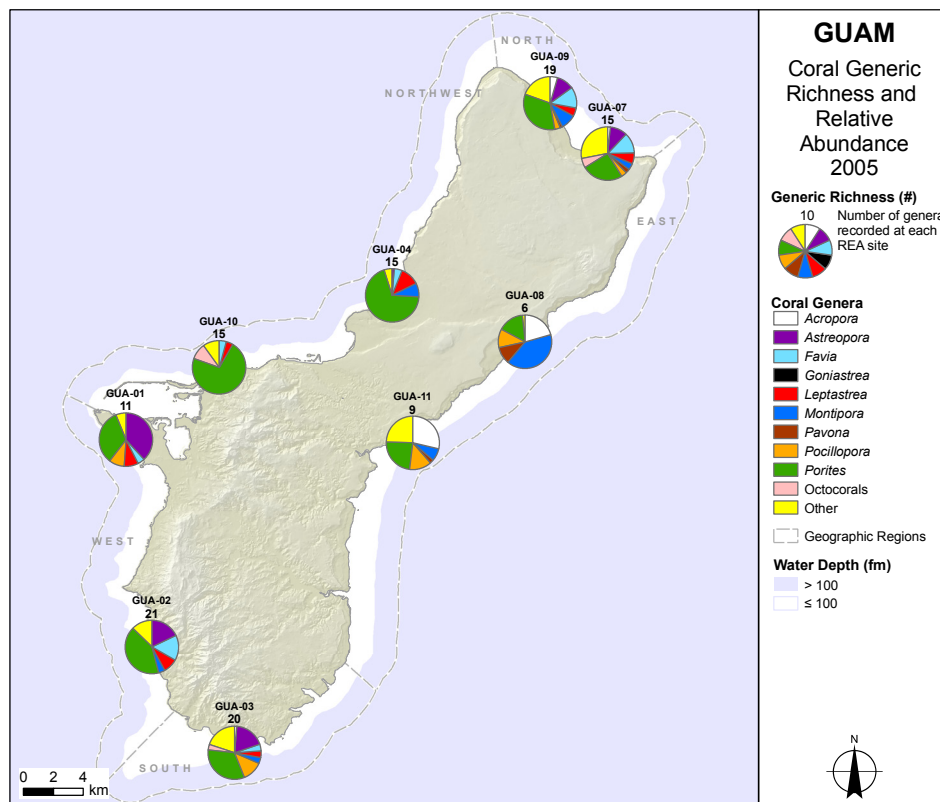

Figure 4.5.1i. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2003 to survey coral genera.

Nine REA benthic surveys of forereef habitats were conducted using the belt-transect method around Guam during MARAMP 2005. At least 28 coral genera were observed around Guam. Generic richness ranged from 6 to 21 with a mean of 14.6 (SE 1.7) coral genera per site (Fig. 4.5.1j). The highest generic diversities were seen at GUA-02 in Cetti Bay in the west region and GUA-03 in the south region with 21 and 20 coral genera, respectively, and the lowest generic diversity was recorded at GUA-08 in the east region. However, due to a diving impairment, the lead coral biologist was unable to survey GUA-08 and GUA-11 in the east region. Instead, these sites were surveyed by a diver who was less experienced in identifying rarer taxa; this fact likely accounts for the lower generic richness at these 2 sites.

Porites and *Astreopora* were the most numerically abundant genera, contributing 38.1% and 10.7% of the total number of colonies enumerated around Guam during MARAMP 2005. All other genera individually contributed < 10% of the total number of colonies. *Porites* dominated the fauna at most sites, with the exception of GUA-08 and GUA-11 in the east region, where colonies of *Acropora* or *Montipora* were more abundant (Fig. 4.5.1j). The greatest relative abundance of *Astreopora* colonies was found at GUA-01 and GUA-02 in the west region and GUA-03 in the south region.

Figure 4.5.1j. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. The pie charts indicate percentages of relative abundance of key coral genera. The belt-transect method was used in 2005 to survey coral genera.

Ten REA benthic surveys of forereef habitats were conducted using the belt-transect method around Guam during MARAMP 2007. At least 34 coral genera were observed around Guam. Generic richness ranged from 14 to 23 with a mean of 17.8 (SE 0.8) coral genera per site (Fig. 4.5.1k). The highest generic diversity was seen at GUA-09 near Jinapsan Point in the north region, and the lowest generic diversities of 14 and 15 coral genera were recorded, respectively, at GUA-01 in the west region and GUA-04 in Tumon Bay.

Figure 4.5.1k. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. The pie charts indicate percentages of relative abundance of key coral genera. The belt-transect method was used in 2007 to survey coral genera.
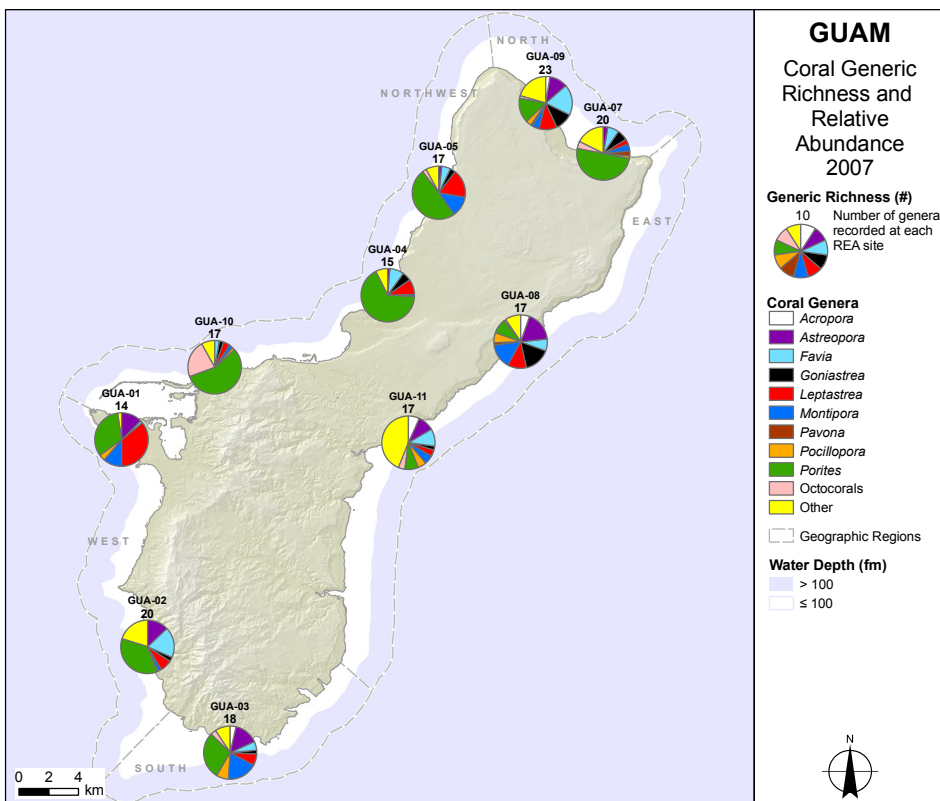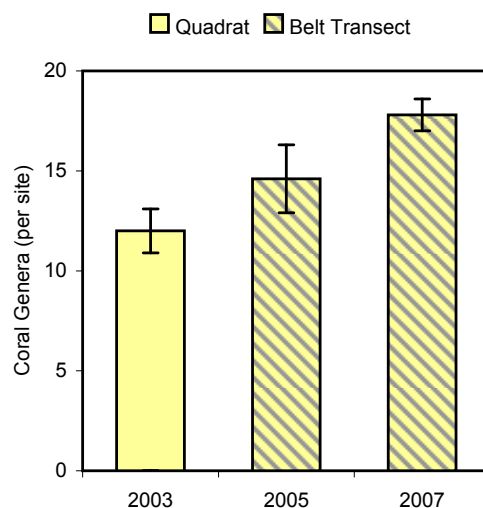
Porites and *Leptastrea* were the most numerically abundant genera, contributing 34.9% and 11% of the total number of colonies enumerated around Guam during MARAMP 2007. All other genera individually contributed < 10% of the total number of colonies. *Porites* dominated the fauna at most sites, although *Leptastrea* was the most numerically abundant genus at GUA-01 in the west region and *Galaxea* was the most numerically abundant genus at GUA-11 north of Pago Bay in the east region (Fig. 4.5.1k). At GUA-03 in the south region and GUA-08 in the east region near Campanaya Point, relative abundance of coral colonies was more evenly distributed among the 10 most common genera.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 6 to 23 on forereef habitats around Guam. Site-specific and overall mean generic-richness values (Fig. 4.5.1l) were higher in 2005 and 2007 with means of 14.6 (SE 1.7) and 17.8 (SE 0.8) coral genera per site than in 2003 with a mean of 12 (SE 1.1) coral genera per site. The variation between 2003 and both 2005 and 2007 is likely because of the difference in the size of the areas in which corals were censused: the survey area in 2005 and 2007 was 50–100 m^2 per site, much larger than the 3.75 m^2 per site in 2003 (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease). Additionally, the only octocoral genus assessed in 2003 was *Heliopora*, whereas all octocoral genera were assessed in 2005 and 2007. The increase between 2005 and 2007 arises because a few colonies of several genera recorded in 2007 were not recorded in previous years (i.e., *Cladiella*, *Cycloseris*, *Lobophyllia*, *Scapophyllia*, and *Stereonepthya*) and because 3 genera of octocorals (*Lobophytum*, *Sarcophyton*, and *Sinularia*) were distinguished in 2007 but pooled together in previous years.

Across the 3 MARAMP survey years, 34 coral genera were observed on forereef habitats around Guam. *Porites*, *Leptastrea*, *Astreopora*, *Favia*, and *Montipora* were important components of the coral fauna. *Porites* was the most numerically abundant component of the coral fauna in each survey year, accounting for 19.8%, 38.1%, and 34.9% of the total number of colonies enumerated around Guam in 2003, 2005, and 2007. *Leptastrea* was the second-most numerically abundant taxon in 2003 and 2007, contributing 16.8% and 11% of the total number of colonies. *Astreopora* was the second-most numerically abundant taxon in 2005, contributing 10.7% of the total number of colonies. *Favia* and *Montipora* were also important components of the coral fauna in 2003, contributing 15% and 12.4% of the total number of colonies.


Figure 4.5.1l. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 to survey coral genera, but the belt-transect method was used in 2005 and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Coral Size-class Distribution

During MARAMP 2003, 8 REA benthic surveys of forereef habitats were conducted around Guam using the quadrat method. The coral size-class distribution from these surveys shows that the majority (63.5%) of corals had maximum diameters ≤ 5 cm (Fig. 4.5.1m). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 25.7%, 9.4%, and 1.4% of colonies recorded. No colonies with maximum diameters > 40 cm were recorded. The highest proportions (97.7% and 94.5%) of small (≤ 10 cm) colonies were found at GUA-01 and GUA-02 in the west region. The highest proportions of midsize colonies (11–40 cm) were found at GUA-06 in Talofofo Bay in the east region with 18.6%, GUA-07 in the north region with 16%, and GUA-05 near Haputo Point in the northwest region with 16%.

Figure 4.5.1m. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2003 to size corals.
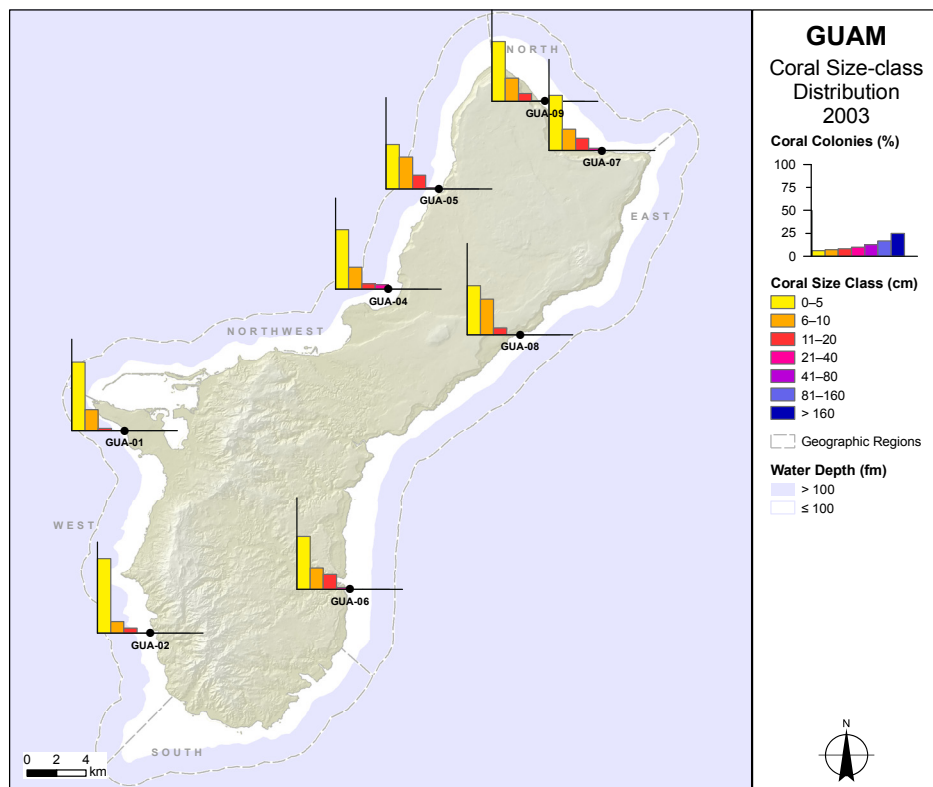
During MARAMP 2005, 9 REA benthic surveys of forereef habitats were conducted around Guam using the belt-transect method. The coral size-class distribution from these surveys shows that the majority (50.9%) of corals had maximum diameters > 10 cm and only 2.1% had maximum diameters > 40 cm (Fig. 4.5.1n). The first 4 size classes (0–5, 6–10, 11–20, and 21–40 cm) accounted for 17%, 32.1%, 31.7 %, and 17.1% of colonies recorded. The highest proportion (84.2%) of midsize colonies (11–40 cm) was found at GUA-08 in the east region, and the highest proportion (74.6%) of small (≤ 10 cm) colonies was found at GUA-01 in the west region.

Figure 4.5.1n. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. The observed size classes are color coded in a size-frequency chart at each REA site. The belt-transect method was used in 2005 to size corals.
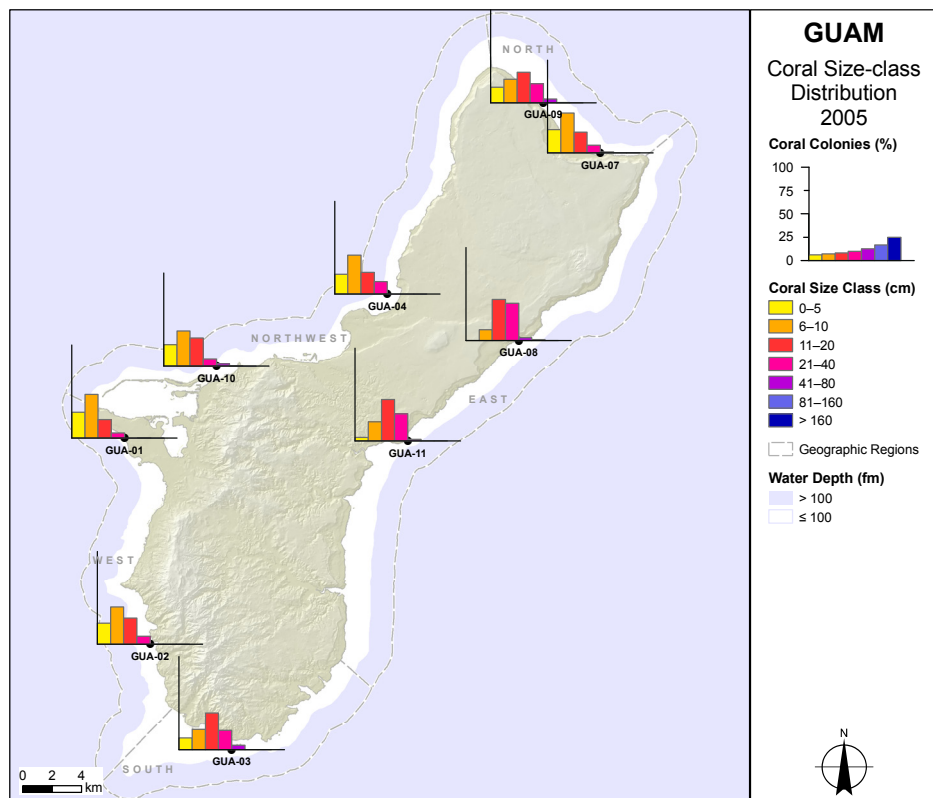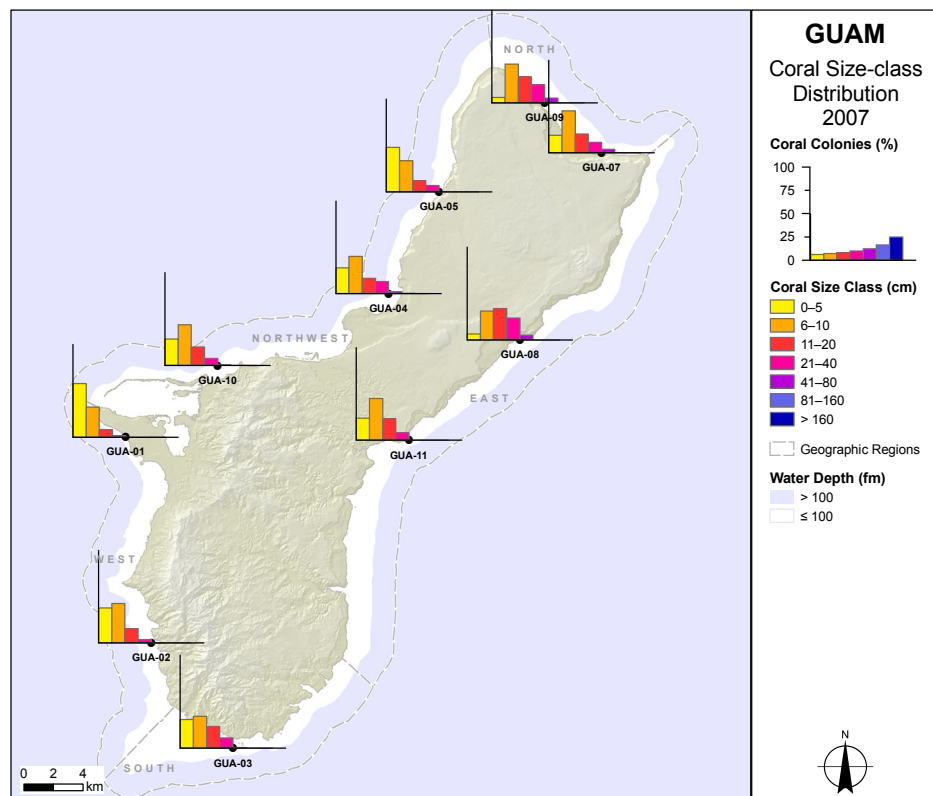
During MARAMP 2007, 10 REA benthic surveys of forereef habitats were conducted around Guam using the belt-transect method. The coral size-class distribution from these surveys shows that the majority (67.5%) of corals had maximum diameters ≤ 10 cm and only 1.8% had maximum diameters > 40 cm (Fig. 4.5.1o). The first 4 size classes (0–5, 6–10, 11–20, and 21–40 cm) accounted for 28.5%, 39%, 20.1 %, and 10.6% of colonies observed. Similar to surveys in 2005, the highest proportion (57.5%) of midsize colonies (11–40 cm) was found at GUA-08 near Campanaya Point in the east region, and the highest proportion (90.1%) of small (≤ 10 cm) colonies was found at GUA-01 in the west region.


Figure 4.5.1o. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The belt-transect method was used in 2007 to size corals.

Site-specific and overall coral size-class distributions on forereef habitats around Guam reflect inherent biases in the methods used to census and size corals. During MARAMP 2003, corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 such quadrats were examined (total survey area = 3.75 m^2), enabling observers to closely inspect and record each coral colony within the quadrat. During MARAMP 2005 and 2007, corals whose center fell within a belt transect (1 or 2 m × 25 m) were tallied and binned into 1 of 7 size classes based on visual estimates of maximum colony diameter. This method is better suited to capturing large colonies, but the larger census area likely reduces the number of very small colonies (≤ 5 cm) that are observed and recorded. For more on these survey methods, see Chapter 2, "Methods and Operational Background, Section 2.4.5: "Corals and Coral Disease."

These methodological biases are reflected in the size-class data by survey year. In 2003, more than half (63.5%) of all colonies censused on forereef habitats around Guam had a maximum diameter ≤ 5 cm, whereas in 2005 and 2007 a far smaller proportion (17% and 28.5%) of colonies were in this smallest size class. Comparing size-class data between survey years when different methods were used is, therefore, inappropriate. For the suite of 9 sites surveyed around Guam with the belt-transect method in both 2005 and 2007, overall size-class distribution did not vary appreciably (Fig. 4.5.1p), although a number of site-specific size-class distributions did vary between 2005 and 2007.

Figure 4.5.1p. Mean coral-colony densities (colonies m-2) by size class from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 to size corals, but the belt-transect method was used in 2005 and 2007. Error bars indicate standard error (± 1 SE) of the mean.
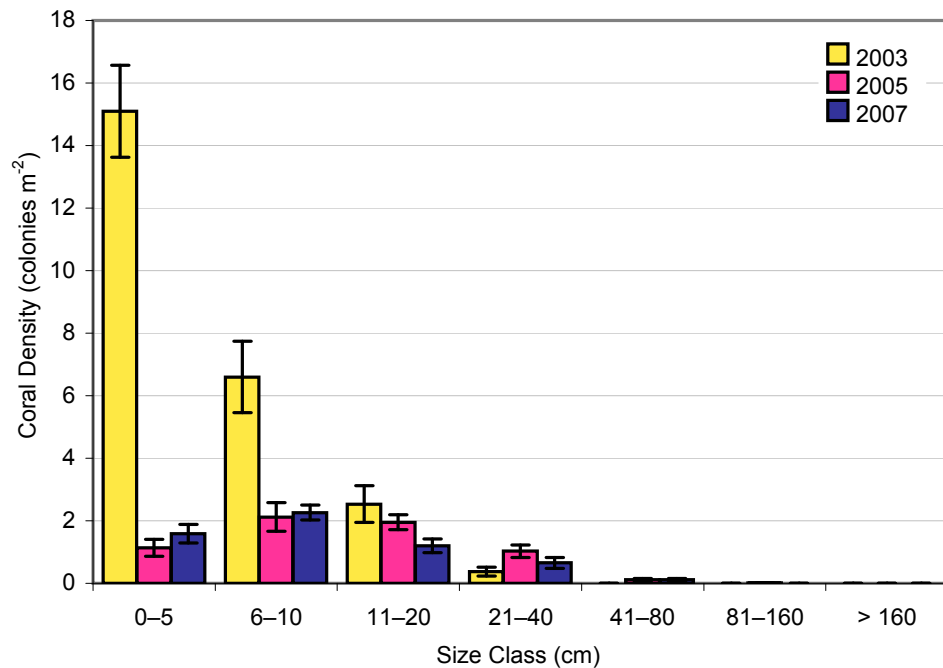
4.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted using the belt-transect method at 10 sites on forereef habitats around Guam, covering a total area of more than 1600 m^2. Surveys detected 85 cases of disease, translating to an overall mean prevalence of 1.4% (SE 0.4), excluding predation. Seven major disease conditions were observed around Guam: bleaching, white syndrome, subacute tissue loss, skeletal growth anomalies, pigmentation response, fungal infection, and other syndromes of unknown etiology. Although all 10 sites contained disease (Fig. 4.5.2a), the greatest numbers of cases were recorded at GUA-05 and GUA-09 with 16 and 12 cases. Relative to colony density, GUA-07 and GUA-09 in the north region had the highest disease prevalence, each with 3.1% (Fig. 4.5.2b; the values of overall prevalence shown in Figure 4.5.2a include predation).

Bleaching was the most common affliction encountered with 39% of cases; bleaching was widely distributed among sites in the east, south, and west regions (Figs. 4.5.2a and b). Although nearly 60% of bleaching cases were recorded on *Astreopora*, corals in the genera *Montipora*, *Porites*, *Goniastrea*, *Favia*, *Platygyra*, and *Psammocora* were also affected. For the most part, bleaching conditions were mild and focal, and overall prevalence only amounted to 0.4% (SE 0.2) around Guam.

Lesions involving pigmentation response on *Porites* were the second-most abundant syndrome, accounting for 26% of disease cases. These lesions were detected as most abundant in the north region at GUA-09 and GUA-07 with overall prevalence values of 2.1% and 2.7%. Often, but not exclusively, lesions appeared associated with areas of tissue loss or fungal and filamentous algal infections.

Conditions involving subacute tissue loss were recorded in the north, northwest, and east regions. Mean overall prevalence of these lesions was low, amounting to 0.3% (SE 0.2) overall around Guam. Of all the sites surveyed, GUA-05 near Haputo Point had the greatest concentration of these lesions with a site-specific overall prevalence of 1.8%. Tissue loss conditions occurred almost exclusively on the genus *Porites*. And, in many instances, these lesions occurred in association with extensive, old partial mortality and turf algal infections.

Other coral diseases present around Guam included fungal infection with a mean overall prevalence of 0.09% (SE 0.04), white syndrome with 0.03% (SE 0.03), algal and cyanophyte infections with 0.02% (SE 0.02), and skeletal growth anomalies with 0.01 (SE 0.01). These conditions were recorded on a variety of coral genera including *Porites* and *Montipora*.

Cases of coral predation attributable to COTS or corallivorous snails, such as snails from the genus *Drupella*, were also observed around Guam, particularly at GUA-04 in Tumon Bay, GUA-11 in Pago Bay, and GUA-09 near Jinapsan Point (Fig. 4.5.2b). The genera *Porites* and *Astreopora* were the main prey of COTS and snails.
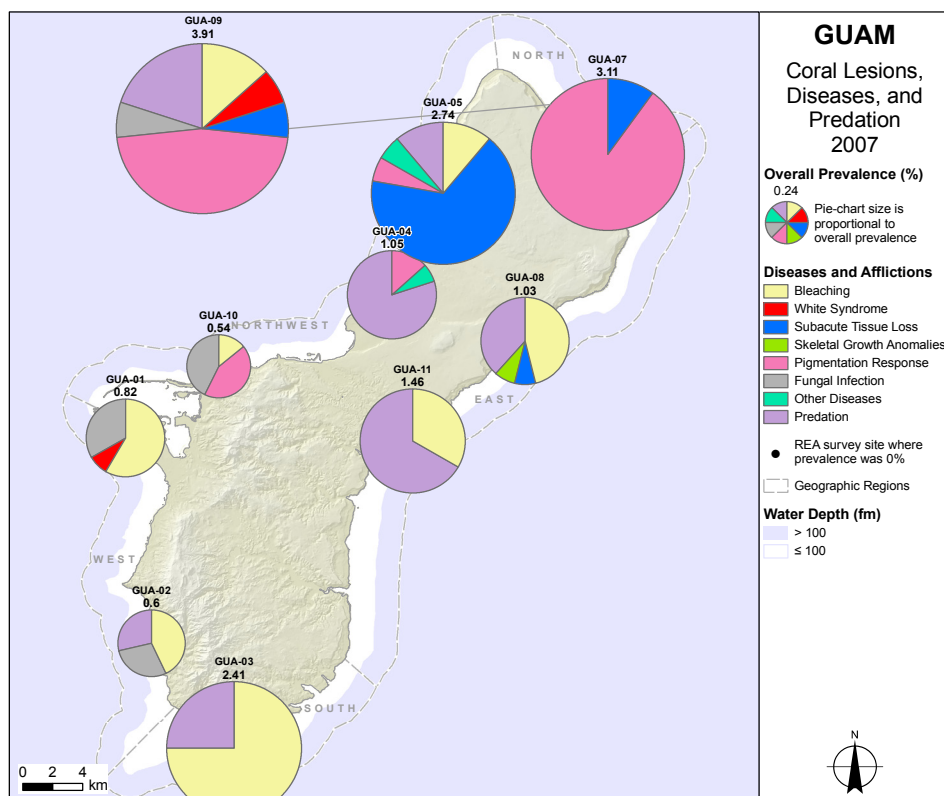
Figure 4.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The color-coded portions of the pie charts indicate disease-specific prevalence.
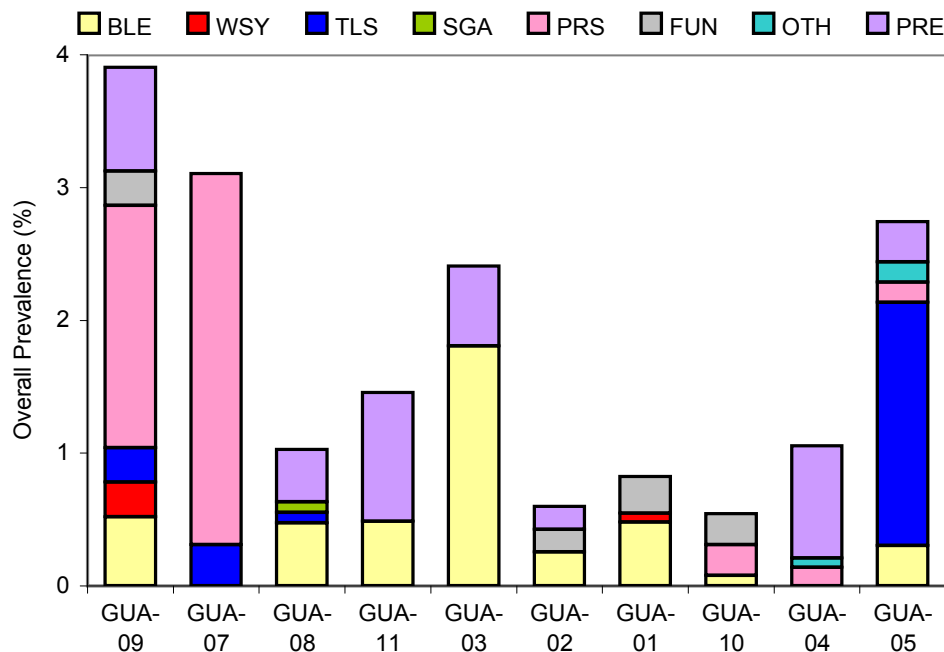
Figure 4.5.2b. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The order of conditions presented in the bars is the same as the order in the legend. BLE: bleaching; WSY: white syndrome; TLS: subacute tissue loss; SGA: skeletal growth anomalies; PRS: pigmentation response; FUN: fungal infection; OTH: algal and cyanophyte infections and other lesions of unknown etiology; PRE: predation by COTS or corallivorous snails.

4.6   Algae and Algal Disease

4.6.1   Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Guam was 46% (SE 1.4). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 82%, within a range of 30.1%–100%, occurred south of Agfayan Bay in the south region (Fig. 4.6.1a, top left panel; for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). Habitats in this area primarily comprised low-relief, spur-and-groove pavement, dominated by species of Halimeda, a genus of calcified, jointed green algae. The Orote Peninsula Ecological Reserve in the west region and Tumon Bay in the northwest region of this island also exhibited high macroalgal cover with means of 68% and 60%. These areas were classified as low to medium-low complexity, pavement habitat—with the exception of a medium-high complexity, continuous-reef section located in Tumon Bay. Remaining surveys found fairly consistent values of algal cover typically within a range of 30.1%–50% and with the high values commonly recorded in pavement habitats of moderately low complexity.

TOAD surveys completed at Guam during MARAMP 2003 were conducted at depths of 15–200 m. Analyses of TOAD video footage obtained from 2 surveys in the middle of the north region and 3 surveys in the east region (2 near Pati Point and 1 near Catalina Point) suggest that macroalgal cover was high with 60%–100%, at least as seen in a majority of images (Fig. 4.6.1a, top left panel). Additionally, 3 TOAD surveys in the west region between Chii Point and Cocos Island and 1 survey near Agat Bay and the Namo River recorded little macroalgae.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Guam was 53% (SE 1.4). The survey with the highest mean macroalgal cover of 86%, within a range of 62.6%–100%, occurred in the south region along low-relief, spur-and-groove pavement habitat near Agfayan Bay (Fig. 4.6.1a, middle left panel). Additional benthic observations included the macroalgal overgrowth of live and dead corals. Surveys recorded the highest macroalgal cover along the Orote Peninsula Ecological Reserve in the west region. From Hagåtña Bay in the northwest region to the area south of Agat Bay in the west region, surveys reported high mean macroalgal cover of 59%–81%. Finally, reefs south-west of Ajayan Bay near GUA-03, reefs northwest of Cocos Island in the west region, and reefs near Ritidian Point in the north region exhibited high macroalgal cover with means of 64%, 65%, and 60%, respectively.

During MARAMP 2005, 7 REA benthic surveys of forereef habitats around Guam were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover from these surveys ranged from 16.7% to 68.6% with an overall mean of 43% (SE 7.6) around Guam. The survey with the highest macroalgal cover of 68.6% occurred in the west region at GUA-02 near Cetti Bay (Fig. 4.6.1b). Relatively high macroalgal-cover values of 64.7% and 54.9% were also found in the west region at GUA-01 and in the south region at GUA-03. The lowest macroalgal cover of 16.7% occurred in Tumon Bay in the northwest region at GUA-04.

Turf-algal cover from these REA benthic surveys in 2005 ranged from 1% to 32.4% with an overall mean of 17 % (SE 4.9). The highest turf-algal cover of 32.4% was observed at GUA-04 in the northwest region. The survey with the lowest turf-algal cover of 1% occurred in the west region at GUA-02.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Guam was 43% (SE 1.6). The survey with the highest mean macroalgal cover of 78%, within a range of 62.6%–100%, occurred in the west region along the reefs of Agat Bay (Fig. 4.6.1a, bottom left panel) in a habitat primarily consisting of moderately sloped, carbonate pavements. Species of Halimeda and the brown alga Padina dominated this substrate with half of the surveyed area exhibiting > 75% macroalgal cover. Two towed-diver surveys completed southwest of Ajayan Bay, along the southern edge of Cocos Lagoon, also reported high macroalgal cover with a mean of 44%, within a range of 5.1%–100%, over spur-and-groove pavement habitat. Species of Halimeda and Padina formed the dominant benthic components. Additionally, the survey north of Pago Bay in the east region with a mean of 61%, within a range of 50.1%–100%, recorded values of mac-roalgal cover that were higher than those values observed in other geographic regions around Guam. Species of the green algae Halimeda and Caulerpa accounted for the majority of coverage among the medium-complexity, spur-and-groove habitat. Remaining surveys reported mean or slightly less than mean values for macroalgal cover—with the exception of 1 survey in the south region off of Cocos Island with a mean of 10% within a range of 5.1%–20%.

During MARAMP 2007, 10 REA benthic surveys of forereef habitats around Guam were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 1% to 45.1% with an overall mean of 24% (SE 4.6) around Guam. Two surveys had the highest macroalgal cover of 45.1%, 1 in the west region at GUA-02 near Cetti Bay and 1 at GUA-04 in the northwest region in Tumon Bay (Fig. 4.6.1c). Relatively high macroalgal-cover values of 32.4% and 28.4% were also found in the east region at GUA-11 north of Pago Bay and in the south region at GUA-03 near the Achang Reef Flat Marine Preserve. The survey with the lowest macroalgal cover of 1% occurred in the east region at GUA-08 near Campanaya Point.

Turf-algal cover from these REA benthic surveys ranged from 31.4% to 70.6% with an overall mean of 50% (SE 4.1). The highest turf-algal cover of 70.6% was observed in the west region at GUA-01. The survey with the lowest turf-algal see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Guam was 13% (SE 0.6). The survey with the highest mean crustose-coralline-red-algal cover of 24%, within a range of 10.1%–40%, occurred in Tumon Bay (Fig. 4.6.1a, top right panel), where the habitat consisted of pavement and continuous reef of low to medium-high complexity. A survey near Ritidian Point, the northernmost tip of this island, reported spur-and-groove pavement habitat of medium to medium-high complexity and a mean crustose-coralline-red-algal cover of 23% within a range of 10.1%–40%. The majority of remaining surveys around Guam reported relatively low cover values for crustose coralline red algae, particularly south of Agfayan Bay, where no cover was observed.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Guam was 4% (SE 0.5). The survey with the highest mean crustose-coralline-red-algal cover of 22.6%, within a range of 0.1%–50%, occurred along the northeast coast at Pati Point (Fig. 4.6.1a, middle right panel) in an area of medium-complexity pavement reefs. Other areas that exhibited comparatively high coverage included Jalaihai Point in the south region and Tumon Bay in the northwest region with mean cover values of 13% and 10%. Pavement, continuous reef, and medium-complexity spur-and-groove habitats were the primary benthic components.
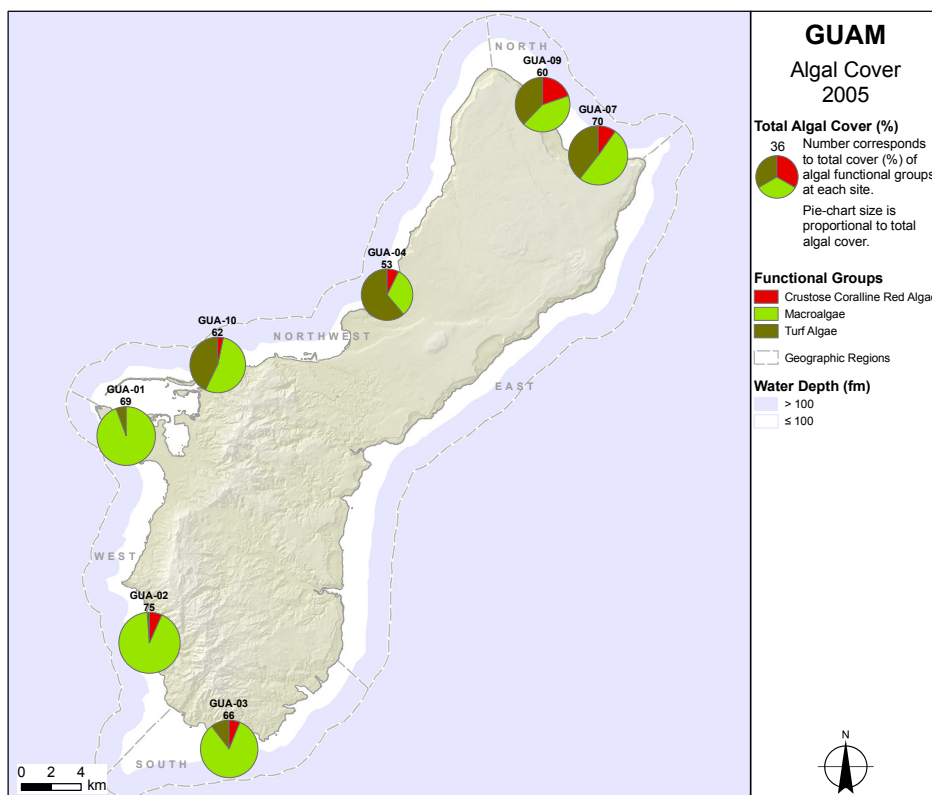
During MARAMP 2005, 7 REA benthic surveys of forereef habitats around Guam were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 11.8% with an overall mean of 5% (SE 1.4). The survey with the highest crustose-coralline-red-algal cover of 11.8% occurred in the north region at GUA-09 near Jinapsan Point (Fig. 4.6.1b). The lowest crustose-coralline-red-algal cover of 0% was recorded at GUA-01 in the west region in the Orote Peninsula Ecological Reserve.

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Guam was 9% (SE 0.6). The survey with the highest mean crustose-coralline-red-algal cover of 23%, within a range of 5.1%–50%, occurred northwest of Cocos Island (Fig. 4.6.1a, bottom right panel), where the predominant habitat type was medium-complexity pavement. Remaining surveys reported relatively low cover values for crustose coralline red algae with slightly elevated cover along the north and east coasts. Continuous pavement reef appeared to dominate the overall benthic structure but sometimes alternated with spur-and-groove habitat.

During MARAMP 2007, 10 REA benthic surveys of forereef habitats around Guam were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red-algal cover ranged from 0% to 7.8% with an overall mean of 2% (SE 0.7). The survey with the highest crustose-coralline-red-algal cover of 7.8% occurred in the northwest region at GUA-10 (Fig. 4.6.1c). The lowest crustose-coralline-red-algal cover of 0% was recorded in the west region at GUA-01 and in the south region at GUA-03.
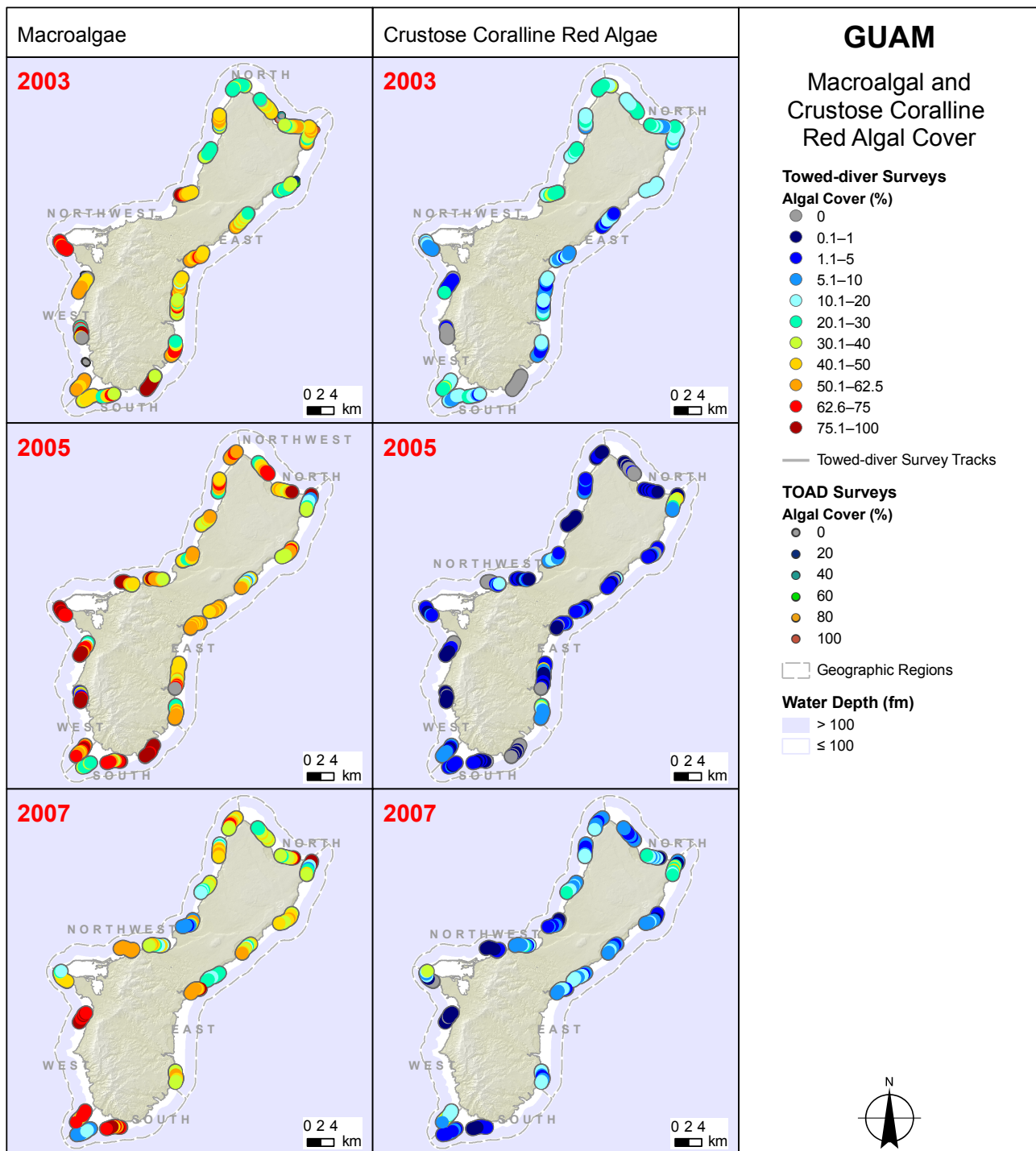
Figure 4.6.1a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m2). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.
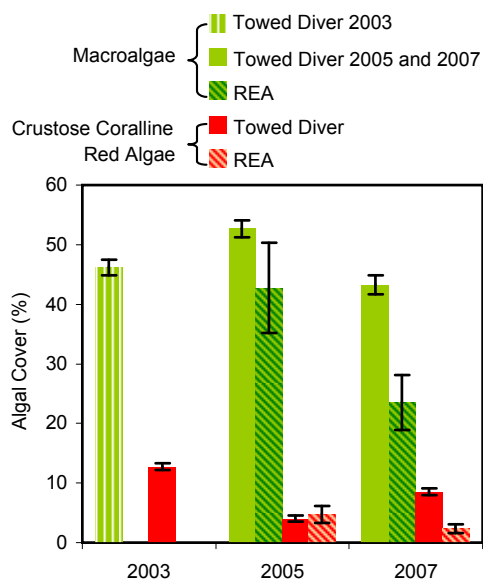
GUAM

Algal Cover
2005

Total Algal Cover (%)

36 Number corresponds to total cover (%) of algal functional groups at each site.

Pie-chart size is proportional to total algal cover.

Functional Groups
- Crustose Coralline Red Algae
- Macroalgae
- Turf Algae

Geographic Regions

Water Depth (fm)
- > 100
- ≤ 100

Figure 4.6.1b. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Guam during MARAMP 2005. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

GUAM

Algal Cover
2007

Algal Cover (%)

36 Number corresponds to total cover (%) of algal functional groups at each site.

Pie-chart size is proportional to total algal cover.

Functional Groups
- Crustose Coralline Red Algae
- Macroalgae
- Turf Algae

Geographic Regions

Water Depth (fm)
- > 100
- ≤ 100
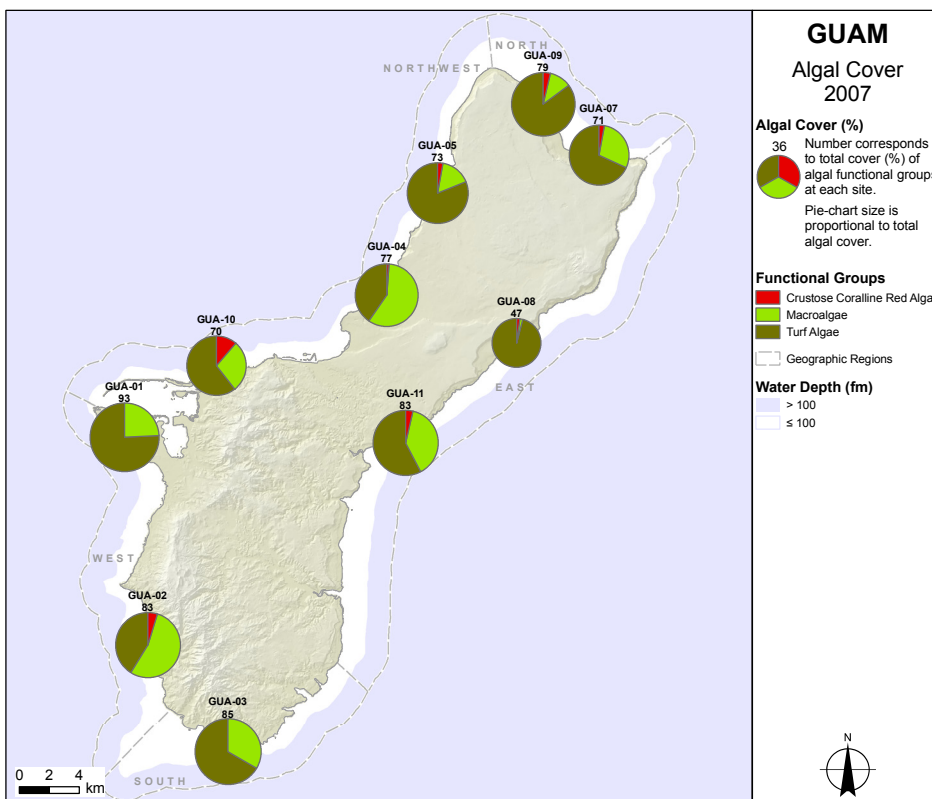
Figure 4.6.1c. Observations of algal cover (%) from REA benthic surveys of forereef habitats conducted using the line-point-intercept method around Guam during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Guam, based on towed-diver surveys of forereef habitats, varied by 10% (Fig. 4.6.1d). In general, macroalgae most commonly inhabited pavement habitats of low-to-medium complexity, and the most noticeable macroalgal genera were *Caulerpa*, *Halimeda*, *Padina*, and the red alga *Asparagopsis*. When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in algal cover (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Figure 4.6.1d. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted in 2003. Error bars indicate standard error (± 1 SE) of the mean.

The highest macroalgal cover recorded in 2005 was 86%—with this observation occurring immediately south of Agfayan Bay. Because this area south of Agfayan Bay was not surveyed during MARAMP 2007, it is unknown how algal populations there in 2007 would compare to algae observed in 2005.

The highest cover of macroalgae was found during MARAMP 2007 in the west region in an area that experienced a significant increase in algal abundance from the previous survey year. The majority of MARAMP 2007 surveys reported decreased cover values, particularly in the areas near Orote Point in the west region, north of Jalaihai Point in the south region, near Pago Bay in the east region, and near Ritidian Point.

Crustose-coralline-red-algal populations around Guam, based on towed-diver surveys of forereef habitats, varied as much as 9% in average cover of the benthos between MARAMP survey years. Crustose coralline red algae most commonly inhabited regions of medium to medium-high complexity.

An overall mean decrease of 9% in crustose-coralline-red-algal cover occurred between MARAMP 2003 and 2005 (Fig. 4.6.1d), although an increase was reported for the area near Pati Point, the most northern point in the east region. The MARAMP 2007 survey conducted in this same area also reported elevated cover values for crustose coralline red algae when compared with other towed-diver surveys conducted around Guam, suggesting that this trend was not likely a result of observer differences.

The greatest decrease in cover of crustose coralline red algae was observed at Tumon Bay, Ritidian Point, Haputo Point, and the area northwest of Cocos Island. An islandwide mean increase of 5% in crustose-coralline-red-algal cover occurred between MARAMP 2005 and 2007. The greatest increases were recorded during surveys near Orote Point, east of Pati Point, and northwest of Cocos Island.
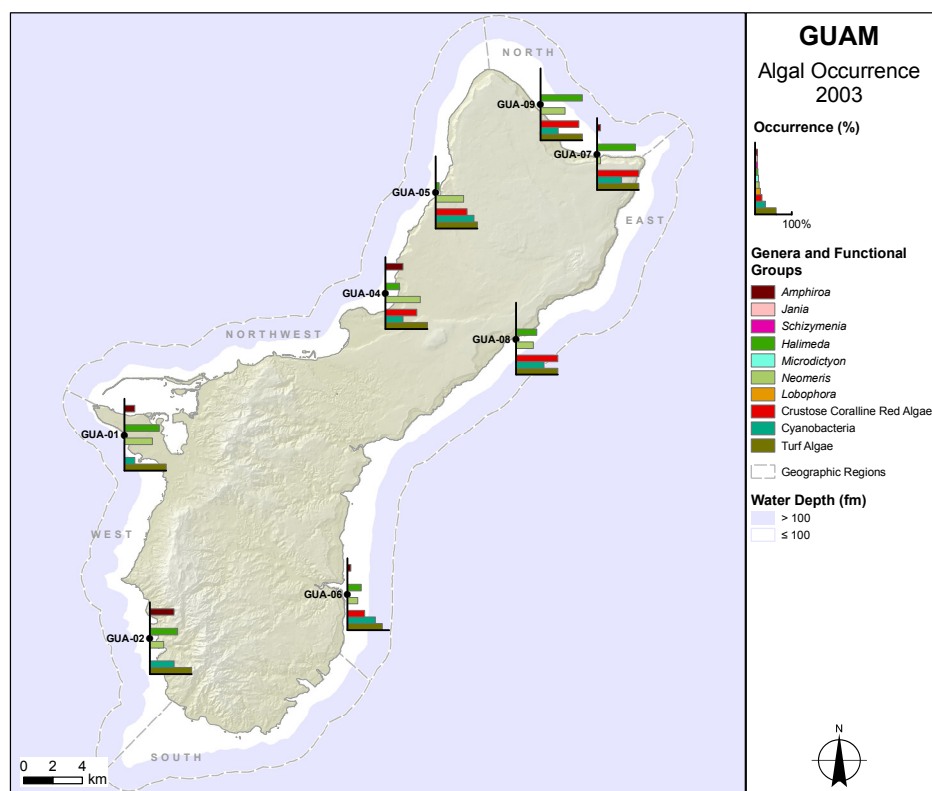
Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites has not been undertaken yet for the southern islands of the Mariana Archipelago. Ultimately, based on this microscopic analysis that may be done in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 8 sites on forereef habitats around Guam. In the field, 22 macroalgal genera (9 red, 10 green, and 3 brown), containing at least 26 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, branched nongeniculate coralline red algae, and cyanophytes—were observed. GUA-01, located in the Orote Peninsula Ecological Reserve, had the highest macroalgal generic diversity with 11 genera, containing 12 species, documented in the field. The lowest macroalgal generic diversity was found at GUA-05 with 4 species representing 4 genera recorded.

Species of the green macroalgal genera *Halimeda* and *Neomeris* were common at every site surveyed around Guam in 2003 (Fig. 4.6.1e), occurring in 58% and 48% of sampled photoquadrats. At the species level, most of the 26 taxa tentatively identified occurred only at 1 or 2 sites, making distinctive spatial patterns of distribution difficult to determine for most macroalgae around Guam. However, some exceptions were found. Both *Halimeda opuntia* and the red alga *Portieria hornemannii* were found only at GUA-07 and GUA-09 in the north region and at GUA-08 in the east region near Campanaya Point, suggesting that oceanographic conditions might favor growth of these algae in these locations. A species of *Padina* was found only along the west coast of Guam, occurring at GUA-04 in Tumon Bay in the northwest region, GUA-01 near Orote Peninusla, and GUA-02 in Cetti Bay. The red alga *Tricleocarpa fragilis* was only recorded during surveys conducted around the southern half of Guam at GUA-01 and GUA-02 in the west region and GUA-06 in the east region.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2003, occurring in 98%, 60%, and 56% of photoquadrats sampled around Guam. Turf-algal communities were ubiquitous at all sites, and, although crustose coralline red algae typically occurred in > 75% of sampled photoquadrats at most sites, this functional group was completely absent from both sites surveyed in the west region: GUA-01 and GUA-02. Cyanobacteria, observed at all sites, were found in 25%–92% of sampled photoquadrats.


Figure 4.6.1e. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

During MARAMP 2005, REA benthic surveys were conducted at 7 sites on forereef habitats around Guam. In the field, 28 macroalgal genera (14 red, 11 green, and 3 brown), containing at least 29 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, branched nongeniculate coralline red algae, and cyanophytes—were observed. GUA-04, located in Tumon Bay in the northwest region, had the highest macroalgal generic diversity with 15 genera, containing 16 species, documented in the field. The lowest macroalgal generic diversity was found at GUA-08 near Campanaya Point in the east region with 8 species representing 8 genera recorded.

Species of the genera *Halimeda* and *Neomeris* were common at every site surveyed around Guam in 2005 (Fig. 4.6.1f), occurring in 95% and 45% of sampled photoquadrats. Although species of the red algal genus Amphiroa were absent or of low abundance at GUA-07 and GUA-09 in the north region and at GUA-08 in the east region, it occurred in 58%–100% of photoquadrats sampled at all other sites. For the majority of the 29 algal species tentatively identified, no strong spatial pattern of distribution was observed around Guam. Exceptions include a species of the red algal genus *Galaxaura* that only occurred at GUA-07 and GUA-09 in the north region and GUA-08, the most northern site in the east region, and species of the green algal genus *Dictyosphaeria* that were found everywhere except 3 sites in the southern half of Guam: GUA-02, GUA-03, and GUA-11. Species of the red algal genus *Martensia* and the calcified green algal genus *Udotea*, in contrast to the trend seen with species of *Dictyosphaeria*, occurred only at locales in the south: GUA-03 and GUA-11 as well as GUA-02 and GUA-03 for each genus, respectively. Species of the genus *Padina* were absent from the east side of Guam, recorded only from the northernmost and southernmost sites (GUA-02, GUA-03, GUA-07, and GUA-09) and from GUA-04 in Tumon Bay in the northwest region.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2005, occurring in 100%, 68%, and 55% of photoquadrats sampled around Guam. Both turf-algal and crustose-coralline-red-algal communities were prevalent at all sites surveyed. However, cyanobacteria were of low abundance at or completely lacking from GUA-02 in Cetti Bay and GUA-03 in the south region.

Figure 4.6.1f. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.
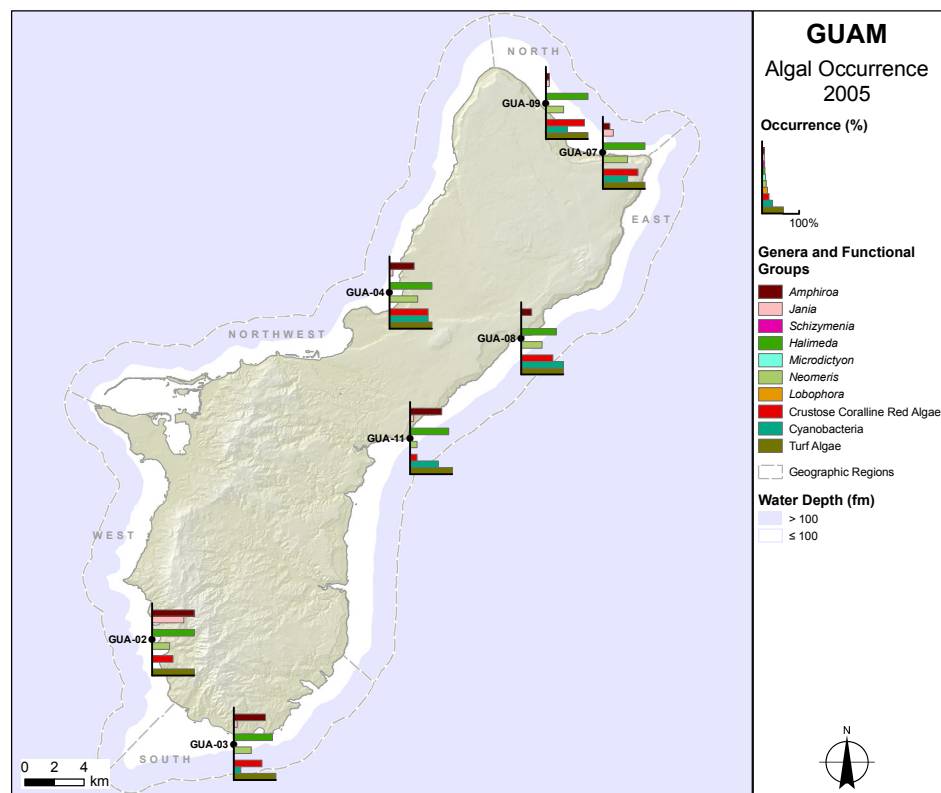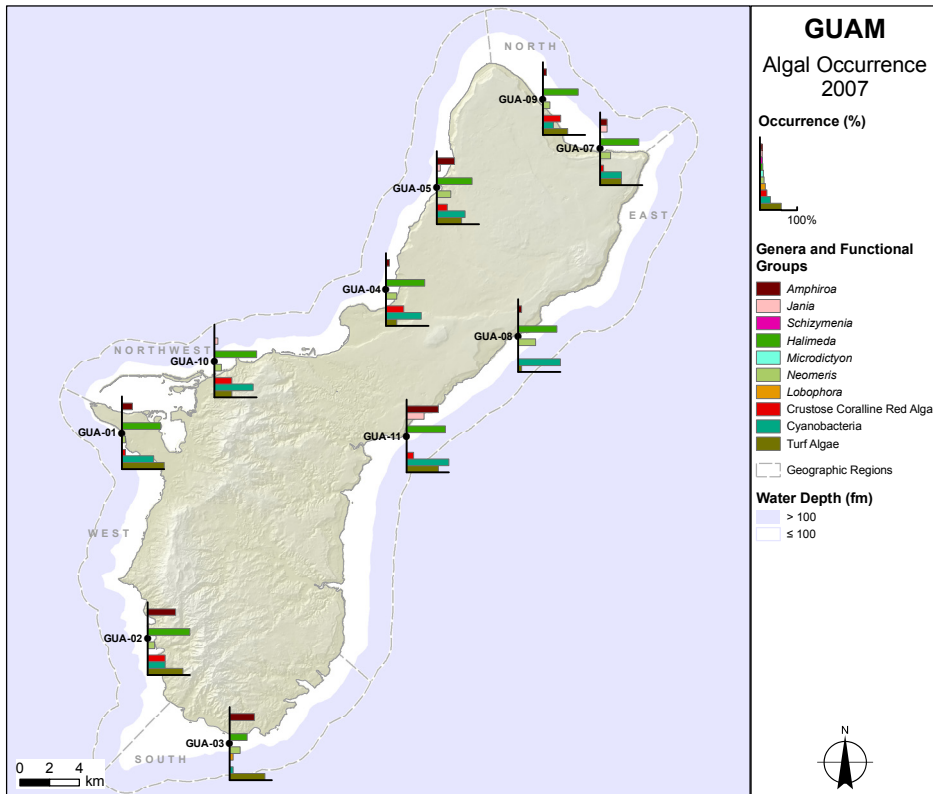

During MARAMP 2007, REA benthic surveys were conducted at 10 sites on forereef habitats around Guam. In the field, 30 macroalgal genera (14 red, 11 green, and 5 brown), containing at least 46 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. GUA-03, located close to the Achang Reef Flat Marine Preserve, and GUA-11 near Pago Bay had the highest number of macroalgal taxa recorded in the field. Although 17 genera were documented at GUA-03 and only 14 at GUA-11, multiple species for some genera led to a total of 18 species observed at each site. The lowest macroalgal generic diversity was found at GUA-08 in the east region near Campanaya Point with 4 species representing 3 genera recorded.

Species of the genus *Halimeda* were ubiquitous at every site surveyed around Guam in 2007 (Fig. 4.6.1g), occurring in 87% of sampled photoquadrats. Of the 46 macroalgal species tentatively identified in the field, only a select few showed any spatial patterns of distribution. *Galaxaura adhaerens*, the green algae *Avrainvillea lacerata* and *Boodlea vanbosseae*,

and the brown alga Dictyota bartayresiana, occurred only at some of the sites on the southern half of Guam: GUA-01, GUA-02, GUA-03, and GUA-11. Alternatively, *Neomeris vanbosseae* and the red alga *Botryocladia skottsbergii* both only occurred at 2 of the sites on the west side: GUA-01 and GUA-10.

Turf algae and cyanobacteria were fairly common in 2007, occurring in 58% and 64% of photoquadrats sampled around Guam. Although crustose coralline red algae occurred in 8%–42% of sampled photoquadrats at most sites, this functional group was also completely absent from GUA-03 near the Achang Reef Flat Marine Preserve. Cyanobacteria occurred at all sites, with individuals being found in 8%–100% of sampled photoquadrats.

Figure 4.6.1g. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

The number of macroalgal genera recorded on forereef habitats around Guam increased from 22 to 28 between MARAMP 2003 and 2005—and rose by an additional 2 genera up to 30 observed during MARAMP 2007. Meanwhile, the increase in species diversity for the same period was more pronounced, increasing from 26 in 2003 to 29 in 2005 and then to 46 in 2007. Differences in survey effort and other factors likely can account for this increase in estimated macroalgal diversity (for information on data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). One less site was surveyed in 2005 than in 2003, although a slight increase in the number of unique genera and species was recorded. Similarly, the number of sites surveyed increased from 8 in 2003 to 10 in 2007, and this greater survey effort may account for the marginal increase in the number of genera observed from 2005 to 2007.

The composition of algal species at 3 sites made much of the northeast coastline unique during most MARAMP survey years. GUA-07 and GUA-09 in the north region and GUA-08 in the east region were the only sites to contain *Halimeda opuntia* and *Portieria hornemannii* in 2003; they were the only sites containing a species of *Galaxaura* and the only ones lacking species of *Amphiroa* in 2005.

Similarly, sites located around the southern half of Guam often contained algal species that were lacking at sites in the north. During MARAMP 2003, GUA-01 near Orote Peninsula, GUA-02 near Cetti Bay, and GUA-06 near Talofofo Bay were the only sites to contain *Tricleocarpa fragilis*. The presence of species of *Martensia* and *Udotea* and the absence of species of *Dictyosphaeria* during MARAMP 2005 were unique to GUA-02, GUA-03 in the south region, and GUA-11 near Pago Bay in the east region. *Avrainvillea lacerata*, *Boodlea vanbosseae*, *Galaxaura adhaerens*, and *Dicyota bartayresiana* were all restricted to GUA-01, GUA-02, GUA-03, and GUA-11 during MARAMP 2007.

The percentages of occurrence of both crustose coralline red algae and turf algae on forereef habitats around Guam differed only slightly from 2003 to 2005, then decreased substantially in 2007 from 68% to 23% and from 100% to 58%, respectively (Fig. 4.6.1h). No subsequent increase in occurrence for macroalgal genera was apparent, suggesting that either the decreases in these functional groups' occurrence values reflected reality (possibly because of seasonal differences) or incongruent definitions for crustose coralline red algae or turf algae were used by observers between MARAMP 2005 and 2007. Cyanobacteria varied only slightly between survey years and occurred in 56%–64% of sampled photoquadrats at each site.

Across the 3 MARAMP survey years, species of the calcified green alga *Halimeda* had the highest occurrence, ranging from 58% in 2003 to 95% in 2005 and 87% in 2007. During the initial survey for MARAMP 2003, species of another calcified green alga *Neomeris* were recorded with the second-highest occurrence, but by 2005, species of the calcified red algal genus *Amphiroa* had the second-highest occurrence and retained that ascendency in 2007. A noticeable increase in percentage of occurrence was observed for species of *Avrainvillea*, *Codium*, *Dictyota*, and *Portieria* from 2003 to 2005, only to be followed by a decrease in 2007 similar to percentages recorded in 2003.

Members of the red algal family Gelidiaceae and species of the genus *Tricleocarpa* were observed in 28% and 19% of the photoquadrats surveyed during MARAMP 2003. By MARAMP 2005, the occurrence of these taxa was reduced to < 2%, and both remained in only 1% of the photoqradrats surveyed during MARAMP 2007.

Figure 4.6.1h. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007.
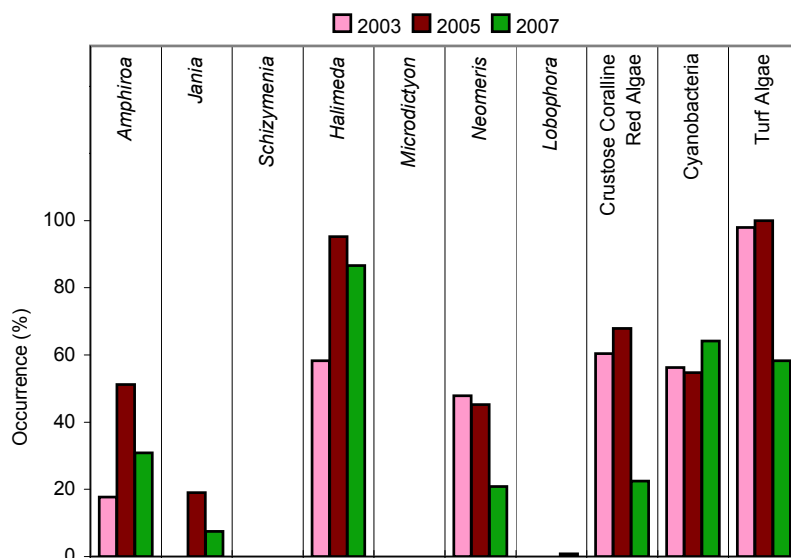
4.6.2   Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 10 sites on forereef habitats around Guam. These surveys covered a total reef area of more than 1600 m^2 and detected 18 cases. These numbers translate to an overall mean density of 1.6 cases 100 m^{-2} (SE 0.8), and disease was found only at reefs in the north and northwest regions (Figs. 4.6.2a). Only 1 major type of coralline-algal disease was observed around Guam: coralline lethal orange disease, present at 4 of the 10 sites surveyed. The greatest density of 8 cases 100 m^{-2} was found at GUA-07 off Jinapsan Point. Tumon Bay also contained disease but did so with a much lower density of 3.6 cases 100 m^{-2}.
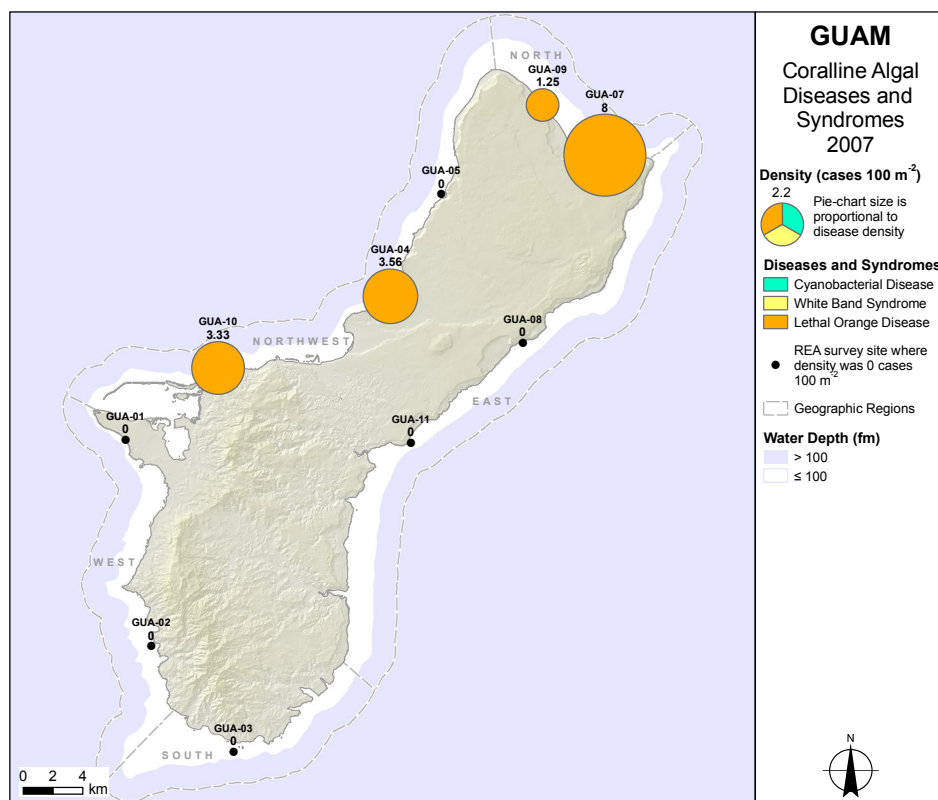
4.7   Benthic Macroinvertebrates

4.7.1   Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Guam through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: "Archipelagic Comparisons."

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 9 REA benthic surveys and 20 towed-diver surveys were conducted, and, in 2005, 9 REA benthic surveys and 23 towed-diver surveys were performed around Guam. In 2007, because of the lack of a scientific diver with expertise in invertebrates, no REA surveys for macroinvertebrates were conducted; however, 19 towed-diver benthic surveys were completed. Also, when considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats around Guam compared to the rest of the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density around Guam—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 4.7.1d, h, l, and p). Because of differences in survey methodology and in REA survey effort, with 9 surveys in both 2003 and 2005 but no surveys in 2007, temporal comparisons of REA data are not presented (see Chapter 2: "Methods and Operational Background," Section 2.4.7: "Benthic Macroinvertebrates").
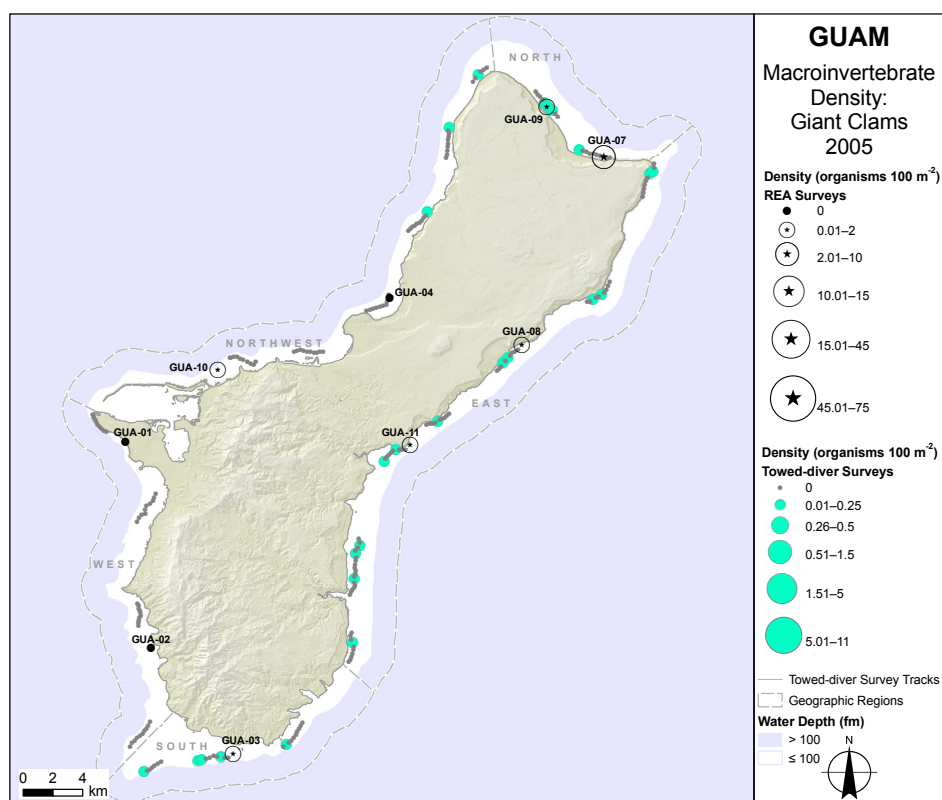
Giant Clams

During MARAMP 2003, species of Tridacna giant clams were observed at 3 of the 9 REA sites surveyed and in 15 of the 20 towed-diver surveys conducted around Guam (Fig. 4.7.1a). The overall mean density of giant clams from REA surveys was 0.55 organisms 100 m^{-2} (SE 0.28), and the islandwide mean density from towed-diver surveys was 0.008 organisms 100 m^{-2} (SE 0.001). Survey results suggest that giant clams were most abundant at REA site GUA-09 in the north region near Jinapsan Point and at GUA-08 in the east region near Campanaya Point (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). At both of these REA sites, the density of giant clams was 2 organisms 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed between Togcha and Talofofo Bays in the east region had the highest mean density of giant clams with 0.018 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.12 organisms 100 m^{-2}. The second-greatest mean density of giant clams from a towed-diver survey was 0.02 organisms 100 m^{-2}, recorded in the south region just west of Ajayan Bay; segment densities ranged from 0 to 0.14 organisms 100 m^{-2}.

Figure 4.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003.
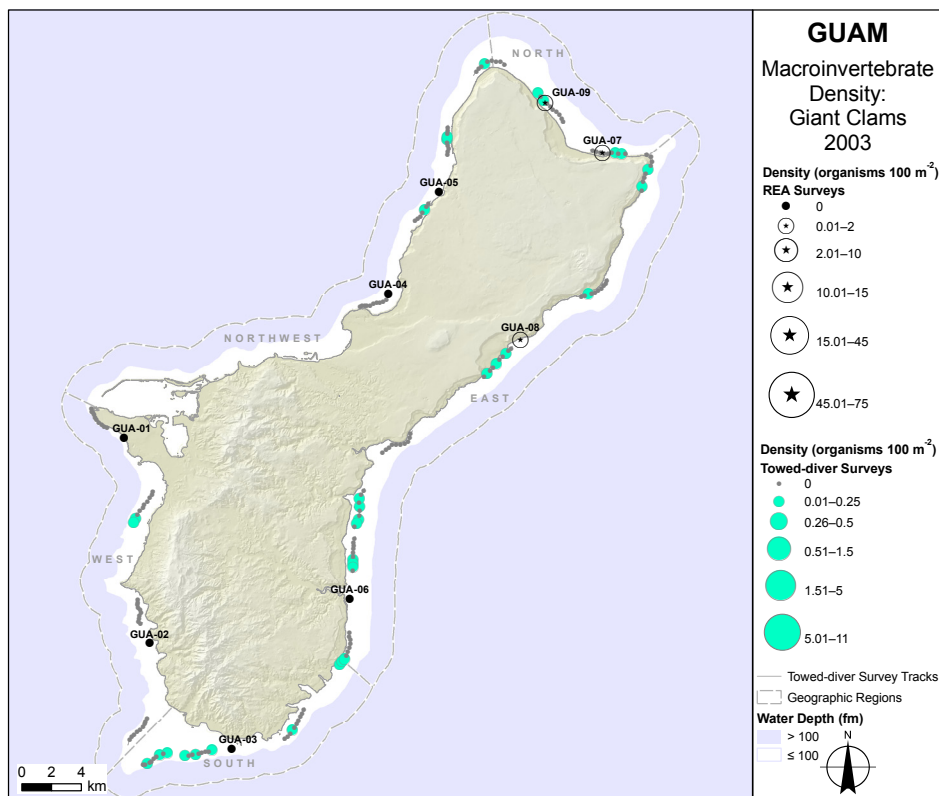

During MARAMP 2005, giant clams were observed at 6 of the 9 REA sites surveyed and in 15 of the 23 towed-diver surveys conducted around Guam (Fig. 4.7.1b). The overall mean density of giant clams from REA surveys was 1 organism 100 m^{-2} (SE 0.31), and the islandwide mean density from towed-diver surveys was 0.006 organisms 100 m^{-2} (SE 0.001). Survey results suggest that giant clams were most abundant at GUA-07, located west of Pati Point in the north region, with 3 organisms 100 m^{-2}, followed by GUA-09 near Jinapsan Point, also in the north region, with 2 organisms 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed between Lujuna and Mati Points in the east region had the highest mean density of giant clams with 0.019 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.1 organisms 100 m^{-2}. The second-greatest mean density of giant clams from a towed-diver survey was 0.017 organisms 100 m^{-2}, recorded in the north region near Jinapsan Point. The next-greatest mean densities were 0.016 and 0.015 organisms 100 m^{-2}, recorded near Pago Bay and north of Cocos Lagoon.

During MARAMP 2007, giant clams were observed in 12 of the 19 towed-diver surveys conducted around Guam (Fig. 4.7.1c) with an islandwide mean density of 0.005 organisms 100 m^{-2} (SE 0.001). Among all towed-diver surveys around this island, the 2 surveys completed in the north region, between Pati and Jinapsan Points, had the highest mean densities of giant clams with 0.019 and 0.015 organisms 100 m^{-2}; segment densities from these 2 surveys ranged from 0 and 0.1 organisms 100 m^{-2}. The third-greatest mean density of giant clams was 0.013 organisms 100 m^{-2}, recorded in the south region just inside Cocos Lagoon and west of Ajayan Bay; segment densities from this survey ranged from 0 to 0.13 organisms 100 m^{-2}.

Figure 4.7.1b. Densities (organisms 100 m⁻²) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005.
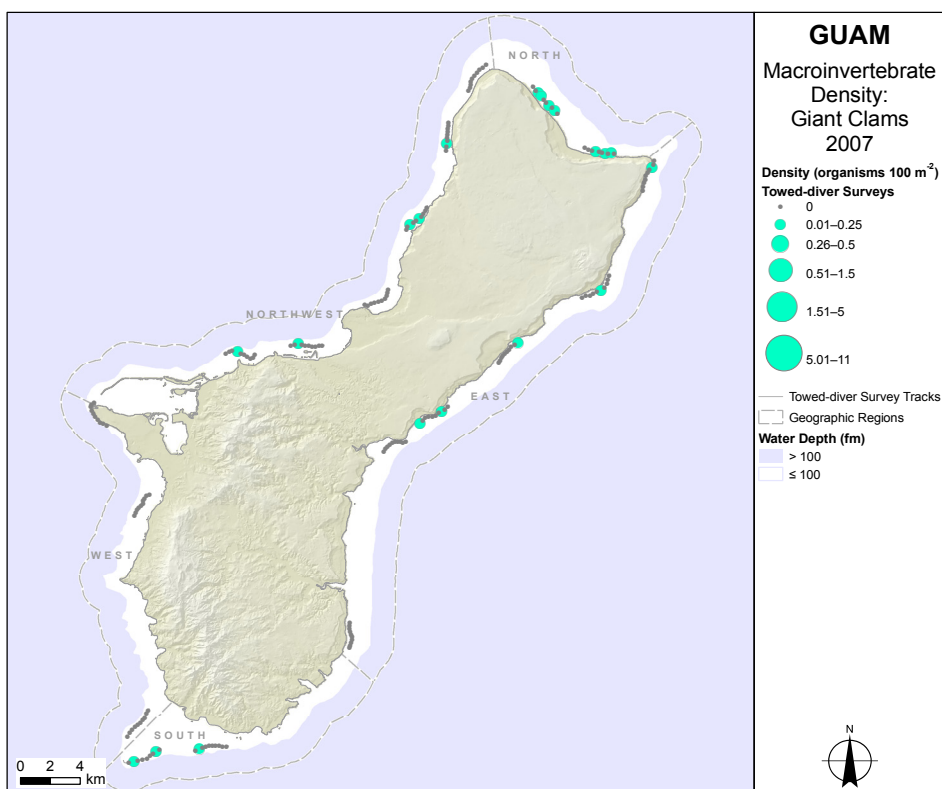
Figure 4.7.1c. Densities (organisms 100 m⁻²) of giant clams from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007.
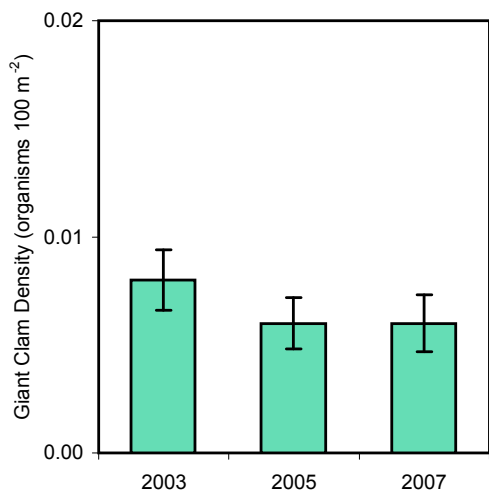
Figure 4.7.1d. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested low abundance of giant clams around Guam during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago (Fig. 4.7.1d). The west region had the fewest giant clams for all survey years. Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Crown-of-thorns Seastars

During MARAMP 2003, no crown-of-thorns seastars (*Acanthaster planci*) were observed at the 9 REA sites surveyed around Guam, but 9 of the 20 towed-diver surveys had recordings of COTS (Fig. 4.7.1e), with an islandwide mean density of 0.05 organisms 100 m^{-2} (SE 0.02). During towed-diver surveys, COTS appeared more concentrated along the west side than in other areas. Among all towed-diver surveys around this island, the survey completed in Agat Bay had the highest mean density of COTS with 0.3 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 1.94 organisms 100 m^{-2}. The second-greatest mean density of COTS from a towed-diver survey of 0.23 organisms 100 m^{-2} was recorded

Figure 4.7.1e. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003.
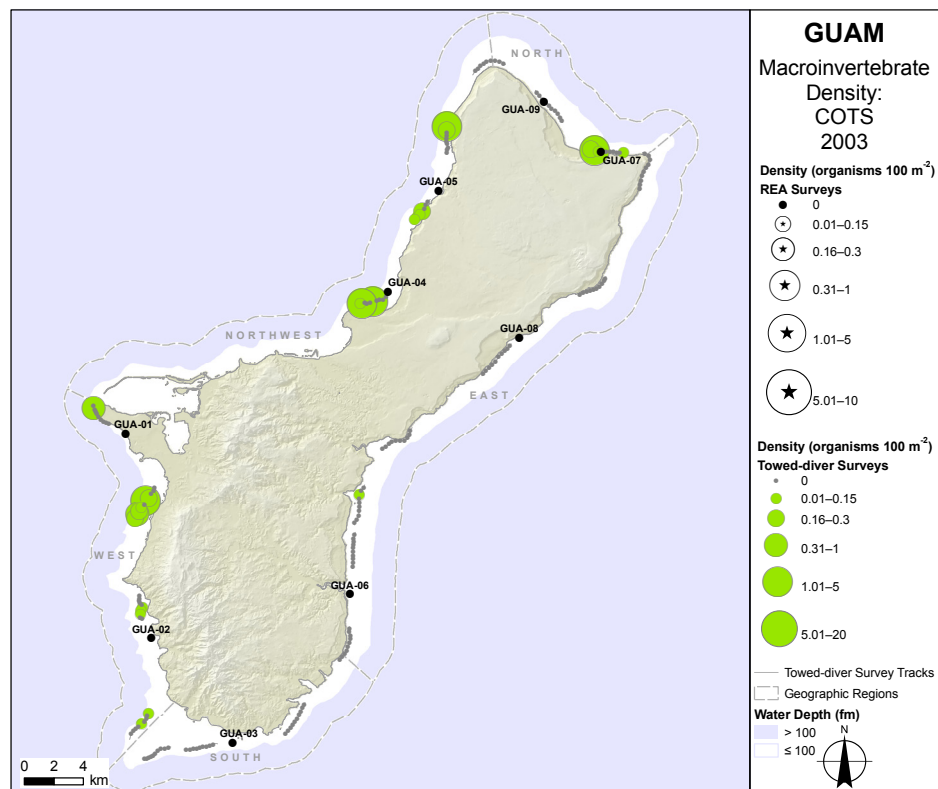
in Tumon Bay; segment densities from this survey ranged from 0 to 1.17 organisms 100 m^{-2}. The towed-diver survey performed south of Uruno Point in the northwest region had a COTS density of 0.14 organisms 100 m^{-2} with segment densities ranging from 0 to 1.19 organisms 100 m^{-2}.

During MARAMP 2005, COTS were observed at 2 of the 9 REA sites surveyed and in 14 of the 23 towed-diver surveys conducted around Guam (Fig. 4.7.1f). The overall mean density of COTS from REA surveys was 0.67 organisms 100 m^{-2} (SE 0.47), and the islandwide mean density from towed-diver surveys was 0.1 organisms 100 m^{-2} (SE 0.03). Survey results suggest that COTS were most abundant at GUA-02 in Cetti Bay with a mean density of 4 organisms 100 m^{-2}, followed by GUA-09 near Jinapsan Point with 2 organisms 100 m^{-2}. During towed-diver surveys, COTS appeared concentrated on the west side of Guam and in the east region between Togcha and Talofofo Bays. Among all towed-diver surveys around this island, the 2 surveys completed nearest to Togcha Bay had the highest mean COTS densities with 0.82 and 0.29 organisms 100 m^{-2}; segment densities from these surveys ranged from 0 to 4.79 organisms 100 m^{-2}. The 2 next-greatest COTS densities were 0.19 and 0.28 organisms 100 m^{-2}, recorded between Uruno and Amantes Points in the northwest region; segment densities from these surveys ranged from 0 to 0.92 organisms 100 m^{-2}.
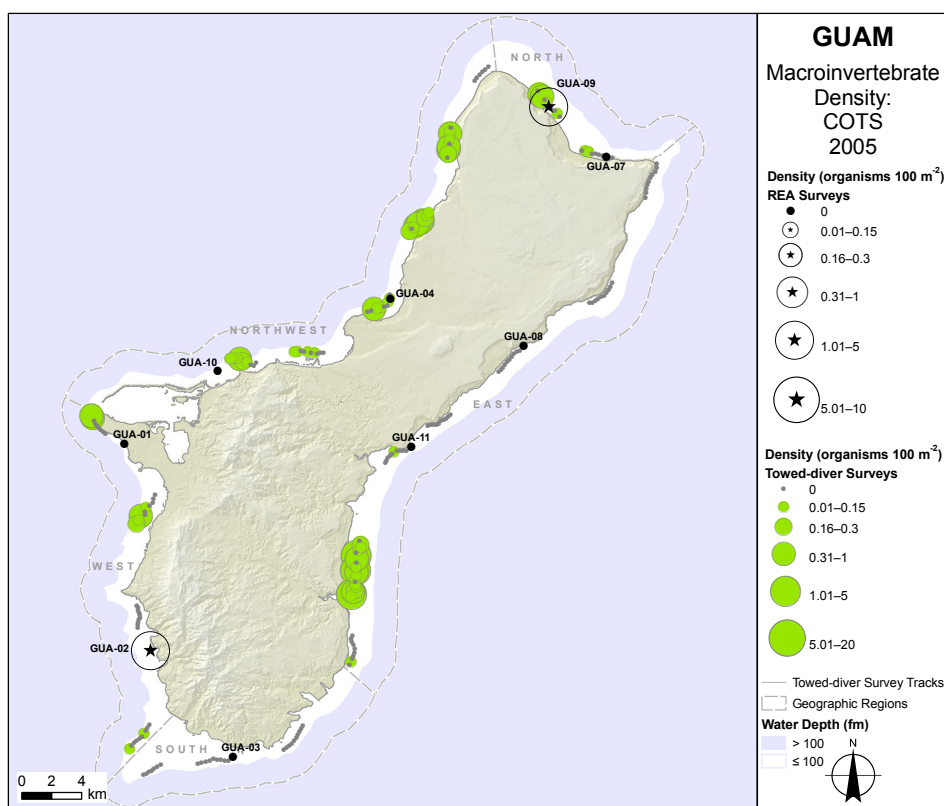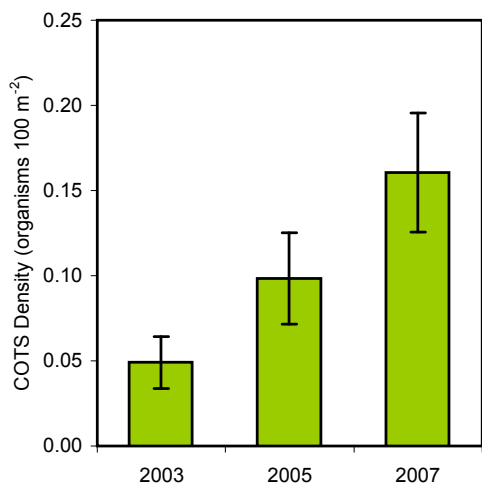

Figure 4.7.1f. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005.

During MARAMP 2007, COTS were observed in 18 of the 19 towed-diver surveys conducted around Guam (Fig. 4.7.1g) with an islandwide mean density of 0.16 organisms 100 m^{-2} (SE 0.04). COTS were found around the entire island; however, they appeared more concentrated in the east and south regions. Among all the towed-diver surveys around this island, the survey completed along Fadian Point had the greatest mean density of COTS with 0.77 organisms 100 m^{-2}; segment densities from this survey ranged from 0.09 to 3.24 organisms 100 m^{-2}. A little farther north, also in the east region, the second-greatest mean density of COTS from a towed-diver survey of 0.55 organisms 100 m^{-2} was recorded near Campanaya Point; segment densities ranged from 0 to 4 organisms 100 m^{-2}. A survey north of Jalaihai Point had a mean density of 0.49 organisms 100 m^{-2} with segment densities ranging from 0 to 2.1 organisms 100 m^{-2}, and a survey in the south near the east side of Cocos Island, had a mean density of 0.41 organisms 100 m^{-2} with segment densities ranging from 0.04 to 2.75 organisms 100 m^{-2}.

Figure 4.7.1g. Densities (organisms 100 m^{-2}) of COTS from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007.
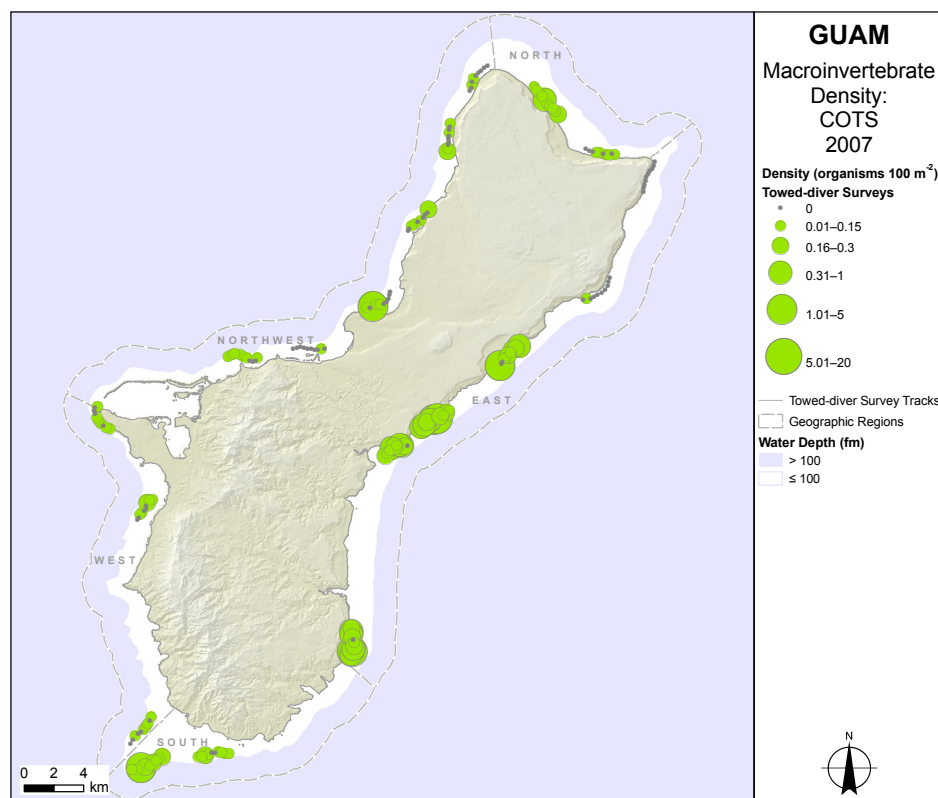
Towed-diver surveys suggested relatively high daytime densities of COTS around Guam during MARAMP 2003, 2005, and 2007, compared to the rest of the Mariana Archipelago, and a linear increase in abundance between MARAMP survey years (Fig. 4.7.1.h). Given that these corallivorous seastars can decimate a reef, understanding whether their observed densities signify an outbreak is important. By means of a manta-tow technique—which uses snorkel divers as observers in a manner similar to the procedure established for using scuba divers to conduct MARAMP towed-diver surveys—Moran and De'ath (1992) defined a potential outbreak as a reef area where the density of A. planci was > 1500 organisms km^{-2} (0.15 organisms 100 m^{-2}) and the level of dead coral present was at least 40%. Using this definition only in terms of density and considering each towed-diver survey as an individual reef area, localized areas with relatively high densities that suggest that they were undergoing an outbreak were found during each MARAMP survey year. Based on MARAMP 2003 surveys, such areas were located in Tumon Bay in the northwest region and in Agat Bay in the west region with densities of 0.23 and 0.3 organisms 100 m^{-2}. During MARAMP 2005, the aforementioned density criterion was met in several surveyed areas: near Haputo and Uruno Points in the northwest region with COTS densities of 0.28 and 0.2 organisms 100 m^{-2}, Jinapsan Point in the north region with 0.18 organisms 100 m^{-2}, and Togcha and Talofofo Bays in the east region with 0.82 and 0.29 organisms 100 m^{-2}. By MARAMP 2007, nearly all surveys along the east shores of Guam between Pagat Point and Cocos Island found densities suggesting outbreaks with a range of 0.24 to 0.77 organisms 100 m^{-2}. Also meeting the criterion in 2007, surveys in Tumon Bay recorded 0.17 organisms 100 m^{-2}.

Figure 4.7.1h. Temporal comparison of COTS mean densities (organisms 100 m^{-2}) from towed-diver benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

MARAMP survey results make evident that COTS populations increased from 2003 to 2005 and again from 2005 to 2007. COTS density naturally fluctuates with food availability and variation in recruitment success (Birkeland and Lucas 1990;

Fabricius et al. 2010; and Yamaguchi 1987). A recruitment pulse could have occurred in 2005 along the east side of this island, for example, and COTS could have possibly increased in density and spread along the east coast by 2007 as the more cryptic juveniles became adults, searching for available food.

Sea Cucumbers

During MARAMP 2003, sea cucumbers were observed at only 2 of the 9 REA sites surveyed and in 15 of the 20 towed-diver surveys conducted around Guam (Fig. 4.7.1i). The overall mean density of sea cucumbers from REA surveys was 2.44 organisms 100 m^{-2} (SE 1.63), and the islandwide mean density from towed-diver surveys was 0.25 organisms 100 m^{-2} (SE 0.04). Survey results suggest that sea cucumbers were most abundant at GUA-04 in Tumon Bay with a mean density of 12 organisms 100 m^{-2} and at GUA-07 west of Pati Point in the north region with 10 organisms 100 m^{-2}. Species from 3 genera were observed during REA surveys: *Thelenota*, *Stichopus*, and *Holothuria*. Only sea cucumber species from the genus *Stichopus* were recorded at GUA-07, whereas species from the genera *Thelenota*, *Stichopus*, and *Holothuria* were observed at GUA-04. Of all recorded sea cucumbers, 73% were species from the genus *Stichopus*.

During towed-diver surveys conducted around Guam in 2003, sea cucumbers were observed predominantly along the west coast. Among all towed-diver surveys around this island, the survey completed north of Cocos Island had the highest mean density of sea cucumbers with 1.26 organisms 100 m^{-2}; segment densities from this survey ranged from 0.21 to 3.32 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 1.09 organisms 100 m^{-2}, recorded just west of Ajayan Bay in the south region, and the next-highest mean density of 0.64 organisms 100 m^{-2} was observed in the north region between Pati and Jinapsan Points.
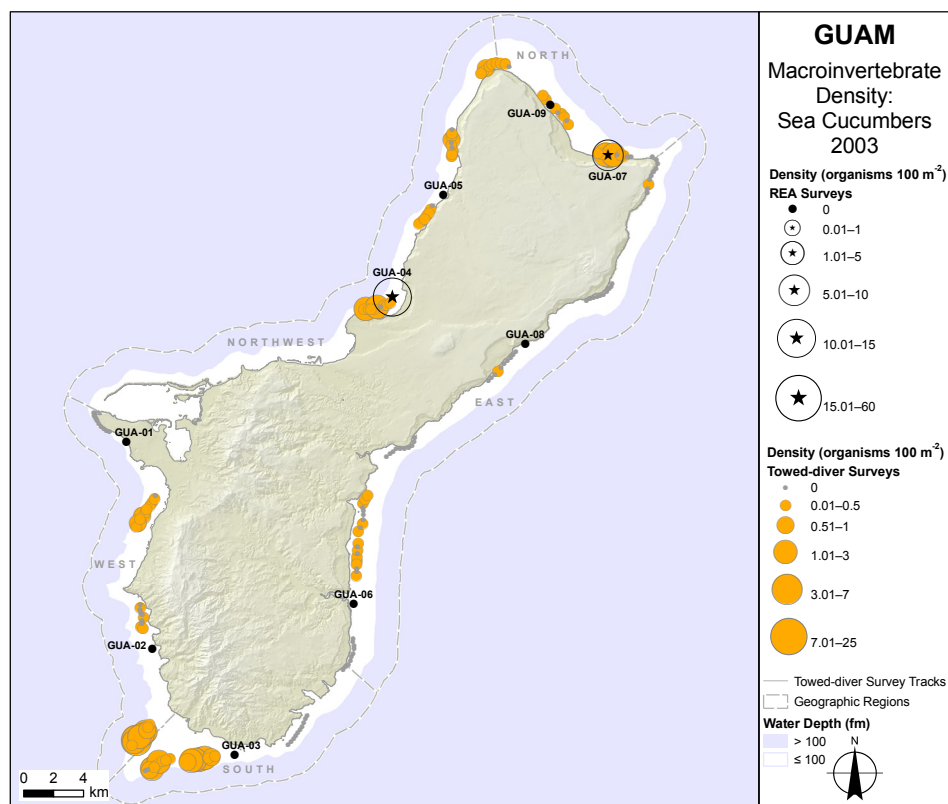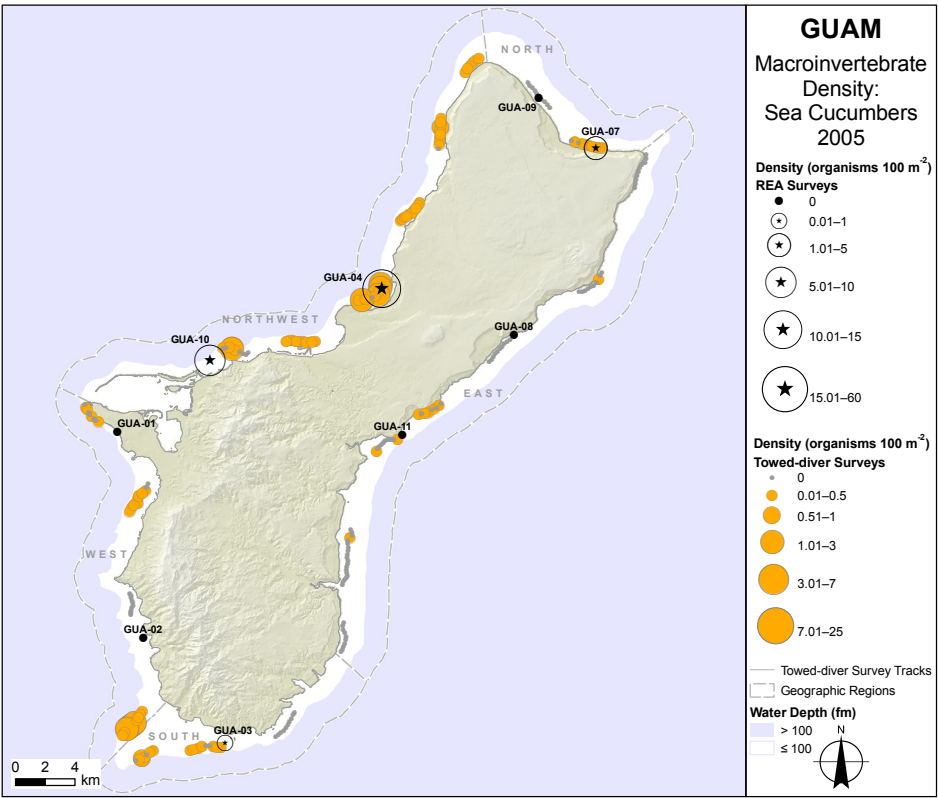

Figure 4.7.1i. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003.
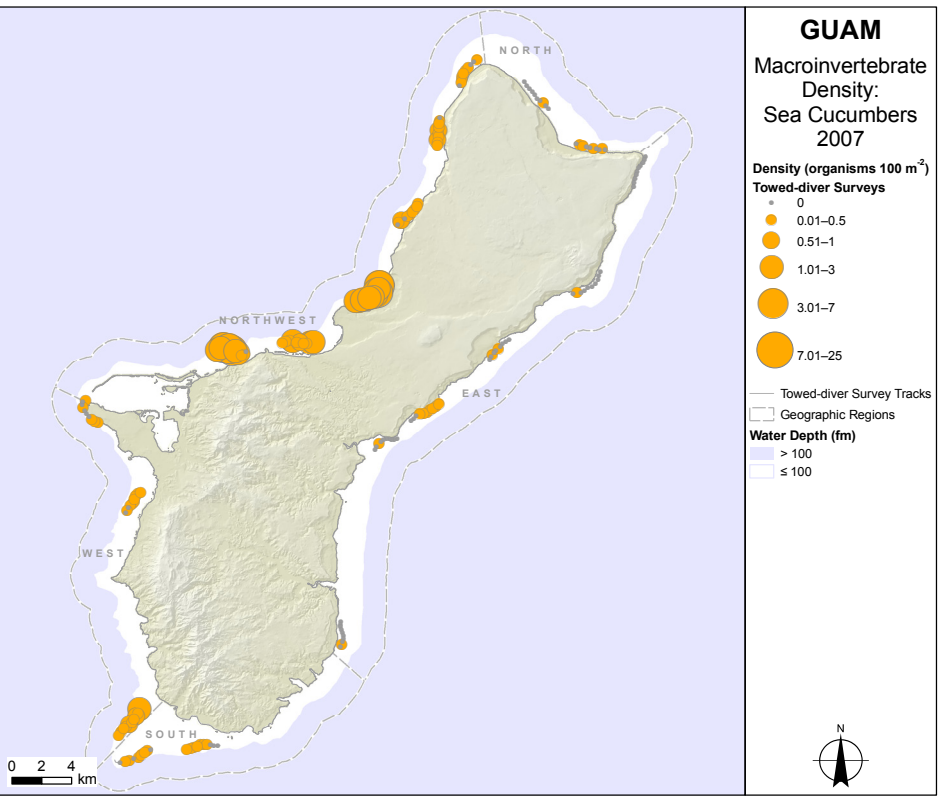
During MARAMP 2005, sea cucumbers were observed at 4 of the 9 REA sites surveyed and in 15 of the 23 towed-diver surveys conducted around Guam (Fig. 4.7.1.j). The overall mean density of sea cucumbers from REA surveys was 2.89 organisms 100 m^{-2} (SE 1.53), and the islandwide mean density from towed-diver surveys was 0.14 organisms 100 m^{-2} (SE 0.02). Survey results suggest that sea cucumbers were most abundant at GUA-04 in Tumon Bay with a mean density of 13 organisms 100 m^{-2}. GUA-10 at Adelup Point, also in the northwest region, had the second-greatest mean density of sea cucumbers with 7 organisms 100 m^{-2}. Sea cucumber species from the genera *Stichopus*, *Actinopyga*, *Bohadschia*, and *Holothuria* were observed; however, species from the genus *Stichopus* represented 80% of recorded sea cucumbers.

During towed-diver surveys conducted around Guam in 2005, sea cucumbers were observed predominantly along the west coast, as they were during MARAMP 2003. Among all towed-diver surveys around this island, the survey completed along the western edge of Cocos Lagoon in the west region had the highest mean density of sea cucumbers with 0.8 organisms 100 m^{-2}; segment densities from this survey ranged from 0.09 to 1.67 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.75 organisms 100 m^{-2}, recorded in Tumon Bay; segment densities ranged from 0 to 1.64 organisms 100 m^{-2}.

Figure 4.7.1j. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005.
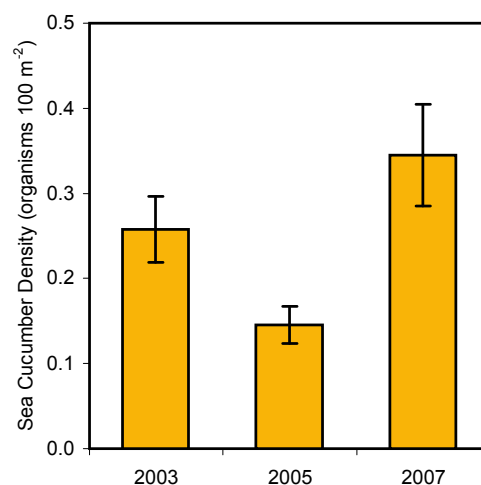

Figure 4.7.1k. Densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007.

During MARAMP 2007, sea cucumbers were observed in 18 of the 19 towed-diver surveys conducted around Guam (Fig. 4.7.1k) with an islandwide mean density of 0.34 organisms 100 m^{-2} (SE 0.06). The 3 surveys with the highest mean densities of sea cucumbers all were performed in the northwest region. Among all towed-diver surveys around this island, the survey completed in Tumon Bay had the greatest mean density of sea cucumbers with 2.36 organisms 100 m^{-2}; segment densities from this survey ranged from 1.42 to 6.76 organisms 100 m^{-2}. The next-highest mean densities of sea cucumbers were 1.86 and 0.71 organisms 100 m^{-2}, recorded around Adelup Point and near Hagåtña Bay.

Towed-diver surveys suggested low daytime abundance of sea cucumbers around Guam during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago. However, during the 3 survey years, high sea cucumber densities were observed in the northwest region between Tumon Bay and Adelup Point. Although sea cucumbers were not recorded to genus during towed-diver surveys, REA surveys suggested that over 90% of the sea cucumbers observed in this region were species from the genus *Stichopus*.

The overall observed mean density of sea cucumbers around Guam was higher in 2007 than in 2003 and 2005 (Fig. 4.7.1l). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Figure 4.7.1l. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 9 REA sites surveyed and in 17 of the 20 towed-diver surveys conducted around Guam (Fig. 4.7.1m). The overall mean density of sea urchins from REA surveys was 9 organisms
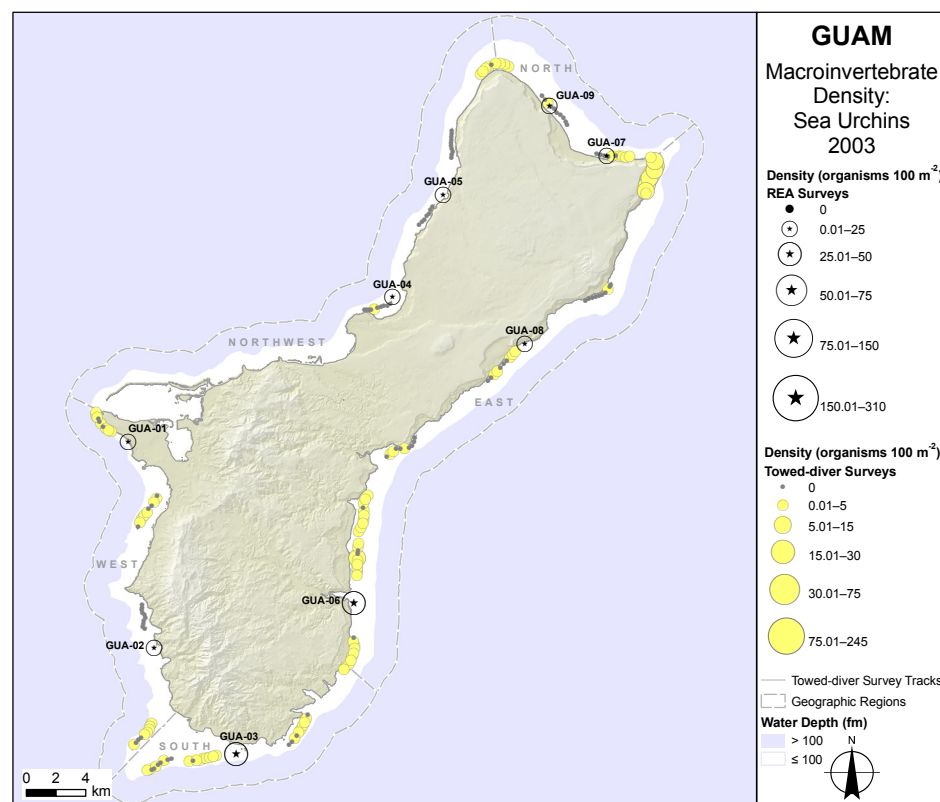
Figure 4.7.1m. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003.
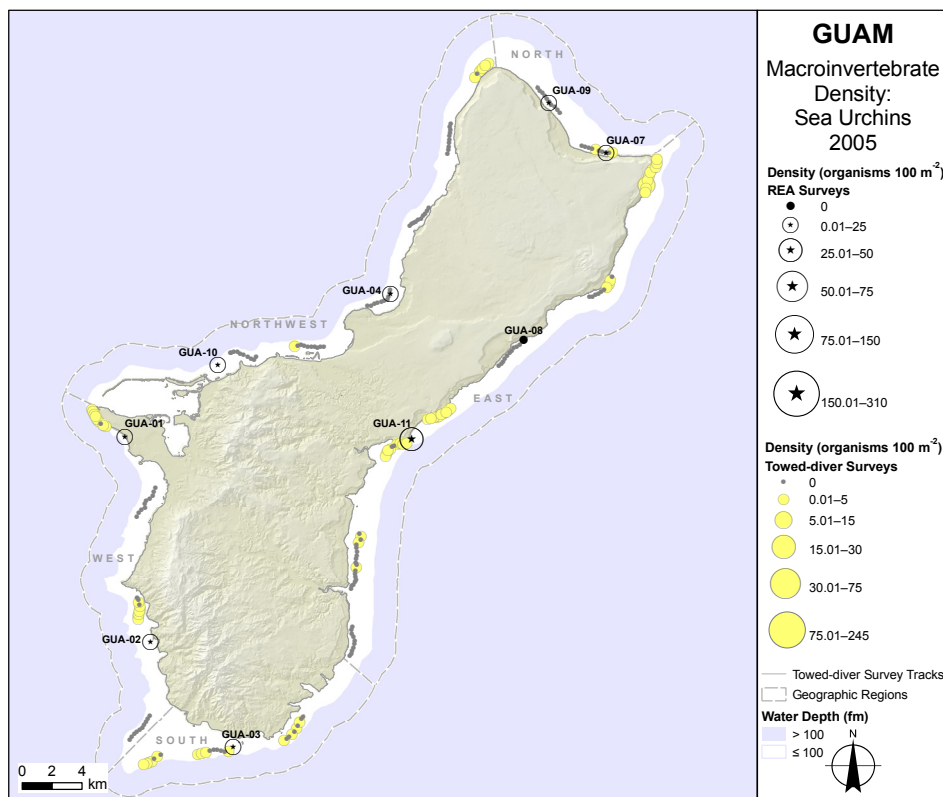
100 m^{-2} (SE 3.7), and the islandwide mean density from towed-diver surveys was 0.95 organisms 100 m^{-2} (SE 0.13). Survey results suggest that sea urchins were most abundant at GUA-03, located in the south region just west of Ajayan Bay, with a mean density of 29 organisms 100 m^{-2} and at GUA-06 in the east region in Talofofo Bay with 27 organism 100 m^{-2}. Rock-boring urchins from the genus *Echinostrephus* were the dominant macroinvertebrates at all sites, accounting for 96% of recorded urchins. GUA-07 east of Pati Point in the north region had the highest species diversity with representatives from the genera *Echinostephus*, *Echinothrix*, and *Diadema*.

Among all towed-diver surveys conducted around Guam in 2003, the survey completed around Pati Point in the east region had the highest mean density of sea urchins at 6.23 organisms 100 m^{-2}; segment densities from this survey ranged from 0.04 to 12.53 organisms 100 m^{-2}. The second-greatest mean density of sea urchins from a towed-diver survey was 2.52 organisms 100 m^{-2}, recorded between Ajayan Bay and Cocos Island in the south region; segment densities ranged from 0 to 3.69 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed at 8 of the 9 REA sites surveyed and in 14 of the 23 towed-diver surveys conducted around Guam (Fig. 4.7.1n). The overall mean density of sea urchins from REA surveys was 7.33 organisms 100 m^{-2} (SE 3.86), and the islandwide mean density from towed-diver surveys was 0.45 organisms 100 m^{-2} (SE 0.07). Survey results suggest that sea urchins were most abundant at GUA-11 in the east region, between Fadian Point and Pago Bay, with a mean density of 35 organisms 100 m^{-2}. The second-greatest density of 17 organisms 100 m^{-2} was recorded at GUA-03 west of Ajayan Bay in the south region. The rock-boring urchin *Echinostrephus* was the dominant macroinvertebrate genus overall and the only one recorded at all sites but one; species from the genus *Echinothrix* were also observed at GUA-11. Species from *Echinostrephus* accounted for 92% of recorded urchins.

Among all towed-diver surveys conducted around Guam in 2005, the survey completed along Fadian Point in the east region had the highest mean density of sea urchins with 2.09 organisms 100 m^{-2}; segment densities from this survey ranged from 0.38 to 4.22 organisms 100 m^{-2}. The second-greatest mean density of sea urchins from a towed-diver survey was 1.98 organisms 100 m^{-2}, recorded during the survey that rounded Pati Point; segment densities ranged from 0.4 to 6.91 organisms 100 m^{-2}.

Figure 4.7.1n. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005.

During MARAMP 2007, sea urchins were observed in 18 of the 19 towed-diver surveys conducted around Guam (Fig. 4.7.1o) with an islandwide mean density of 1 organisms 100 m^{-2} (SE 0.23). Among all towed-diver surveys around this island, the survey that rounded Pati Point had the highest mean density of sea urchins with 12.93 organisms 100 m^{-2}; segment densities from this survey ranged from 6.77 to 16.68 organisms 100 m^{-2}. The second-greatest mean density of sea urchins was 2.76 organisms 100 m^{-2}, recorded during the survey near Orote Point in the west region; segment densities ranged from 0 to 7.93 organisms 100 m^{-2}.
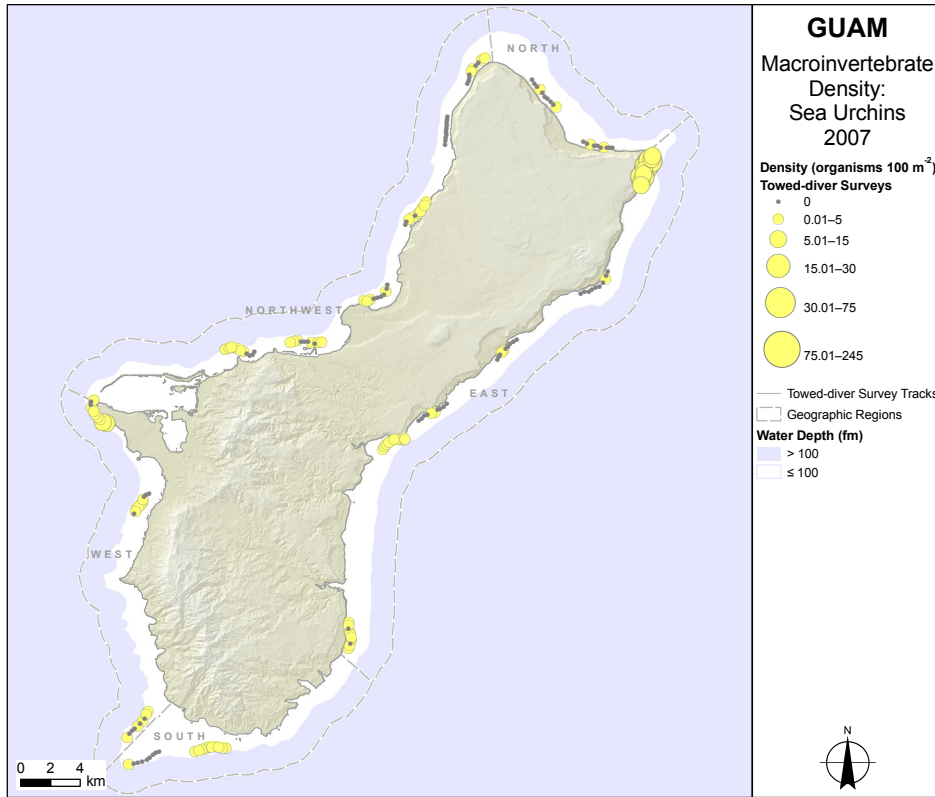
Figure 4.7.1o. Densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007.

Towed-diver surveys suggested low daytime abundance of sea urchins around Guam during MARAMP 2003, 2005, and 2007, compared to the rest of the Mariana Archipelago. The overall observed mean density of sea urchins around Guam was higher in 2007 than in 2005 (Fig. 4.7.1p). Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys"). Although sea urchins were not recorded down to the genus level during towed-diver surveys, REA surveys suggested that more than 90% of the sea urchin species observed around Guam were rock-boring urchins from the genus *Echinostrephus*.
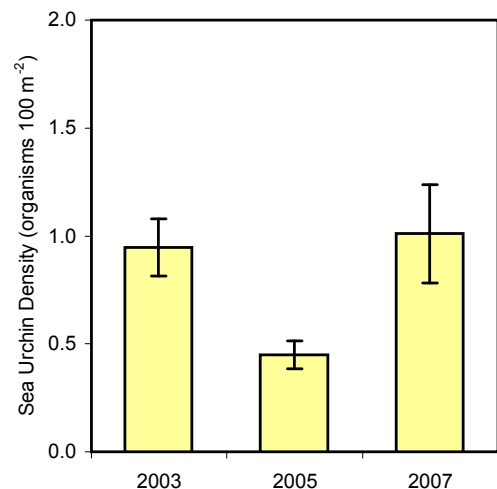
Figure 4.7.1p. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.
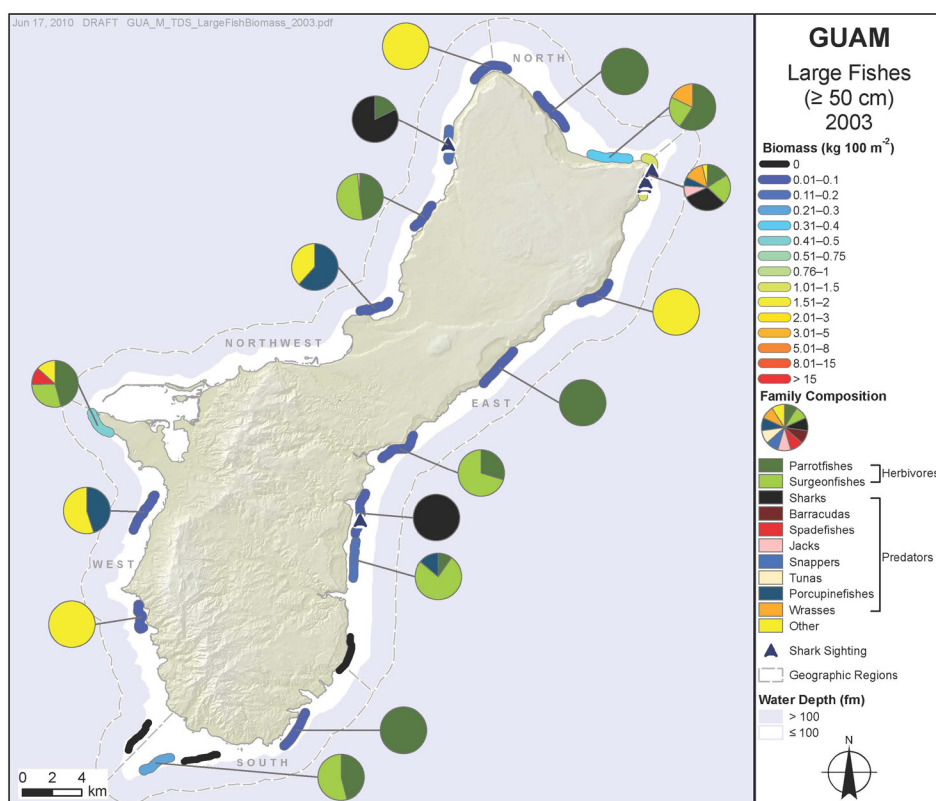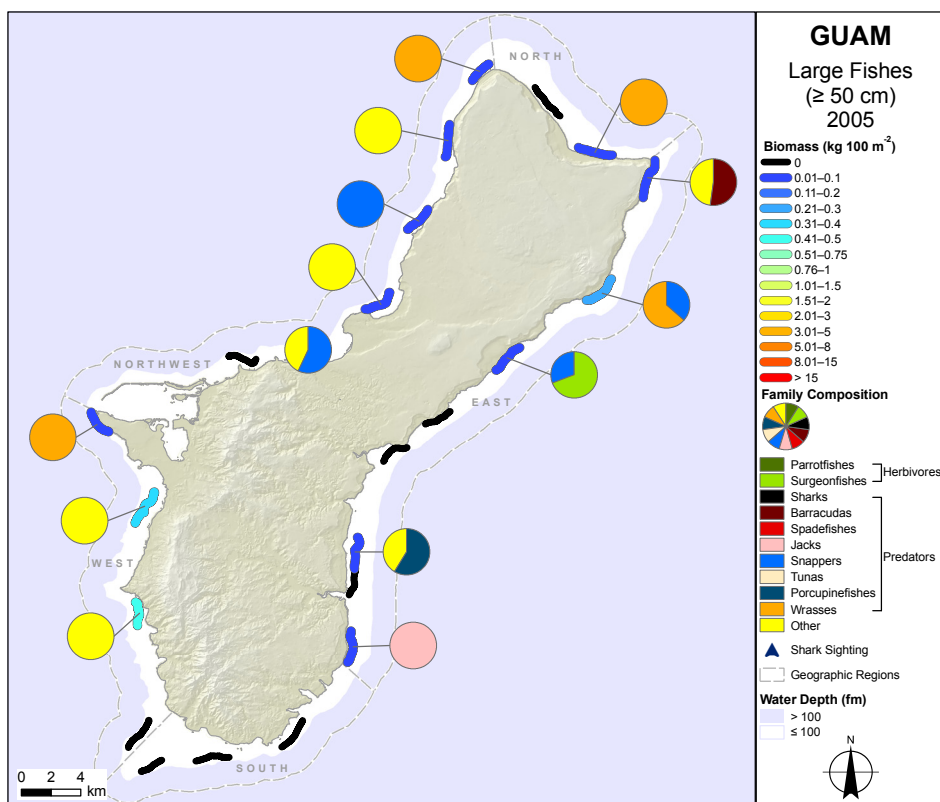
4.8   Reef Fishes

4.8.1   Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 20 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Guam. The overall estimated mean biomass of large fishes around this island, calculated as weight per unit area, was 0.14 kg 100 m^{-2} (SE 0.05), a low value compared to other survey areas in the Mariana Archipelago. No clear spatial patterns were seen in the distribution of large-fish biomass around Guam (Fig. 4.8.1a). Parrotfishes (Scaridae) accounted for the greatest proportion (29%) or 0.04 kg 100 m^{-2} of overall mean large-fish biomass. The filament-finned parrotfish (*Scarus altipinnis*) was the most abundant parrotfish species, contributing more than 30% of parrotfish biomass. Surgeonfishes (Acanthuridae) composed the second-greatest proportion (27%) of overall large-fish biomass, and the bulbnose unicornfish (*Naso tonganus*) was the most abundant surgeonfish species. Five reef sharks (Carcharhinidae) were observed around Guam, and 4 of them were seen along the northern coasts of this island: 3 near Pati Point in the east region and 1 just south of Uruno Point in the northwest region (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). These sharks comprise 3 blacktip reef shark (*Carcharhinus melanopterus*) and 2 whitetip reef shark (*Triaenodon obesus*).

Figure 4.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Guam during MARAMP 2003. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

During MARAMP 2005, 23 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Guam. The overall estimated mean biomass of large fishes around this island was 0.06 kg 100 m^{-2} (SE 0.03), a value lower than the already low biomass observed in 2003. Only select surveys in the west region and the northern part of the east region showed moderate biomass (Fig. 4.8.1b). The eagle ray (*Aetobatus narinari*) accounted for the greatest proportion (33%) of islandwide mean large-fish biomass with 4 individuals recorded during 1 survey. Wrasses (Labridae) and snappers (Lutjanidae) were also abundant, contributing 21% and 11% of overall mean large-fish biomass around Guam. The humphead wrasse (*Cheilinus undulatus*) was the most abundant wrasse species with 3 individuals constituting biomass of 0.01 kg 100 m^{-2}. The twinspot snapper (*Lutjanus bohar*) was the most abundant snapper species, composing more than 90% of snapper biomass. No sharks were observed during this survey period.

Figure 4.8.1b. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Guam during MARAMP 2005. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.
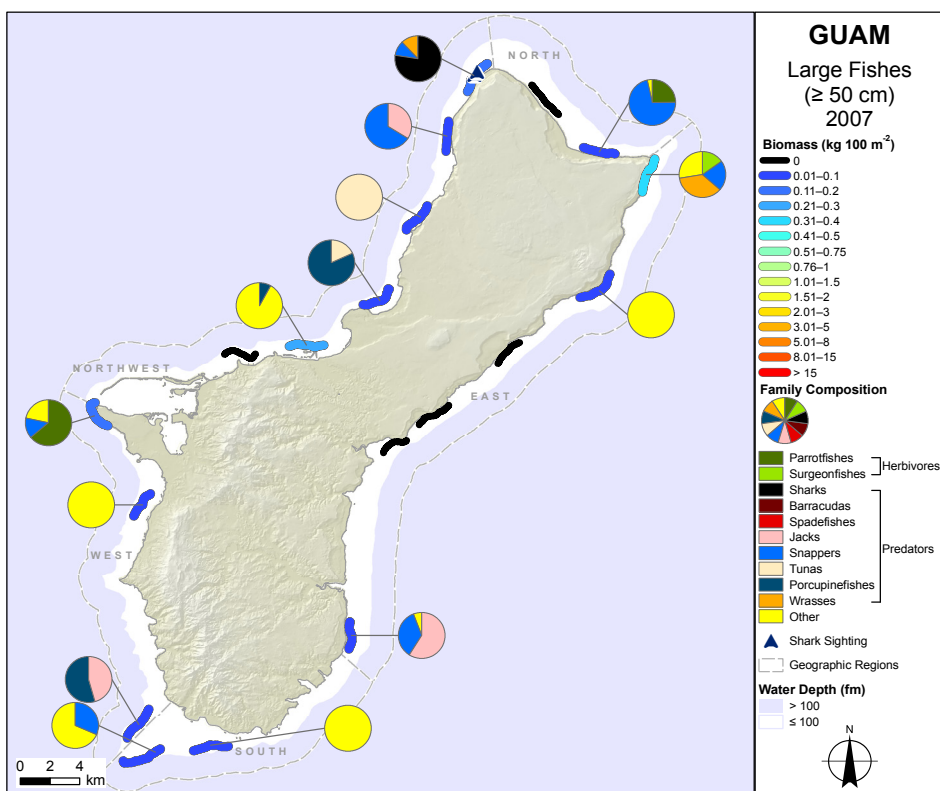
During MARAMP 2007, 19 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Guam. The overall estimated mean biomass of large fishes around this island was 0.07 kg 100 m^{-2} (SE 0.02), a low value compared to other survey areas in the Mariana Archipelago and consistent with the low values observed around Guam in 2005. Biomass values for large fishes were highest in the northwest region and near Pati Point, the northernmost tip of the east region; however, biomass levels in these areas were not anomalously higher than in other survey areas around

Figure 4.8.1c. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Guam during MARAMP 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

this island (Fig. 4.8.1c). Similar to observations made in 2005, eagle ray accounted for the greatest proportion (27%) of islandwide large-fish biomass with 2 individuals contributing 0.03 kg 100 m^{-2} to overall mean large-fish biomass. Snappers composed the second-greatest proportion (15%) of overall mean large-fish biomass around Guam, with the twinspot snapper accounting for more than 60% or 0.01 kg 100 m^{-2} of snapper biomass. Near Ritidian Point in the northwest region, 2 reef sharks were observed: 1 grey reef shark (*Carcharhinus amblyrhynchos*) and 1 whitetip reef shark. Other notable observations included sightings of 3 humphead wrasse and 3 dogtooth tuna (*Gymnosarda unicolor*) during this survey period.

Large-fish biomass from towed-diver surveys of forereef habitats was generally higher during MARAMP 2003, with an islandwide mean of 0.14 kg 100 m^{-2} (SE 0.05), than during later survey periods, when islandwide means were 0.06 kg 100 m^{-2} (SE 0.03) in 2005 and 0.07 kg 100 m^{-2} (SE 0.02) in 2007 (Fig. 4.8.1d). Decreases in sightings of large parrotfishes, surgeonfishes, and reef sharks were responsible for this pattern: 5 reef sharks were sighted around Guam in 2003, none in 2005, and only 2 in 2007. Shark sightings generally occurred at this island's more remote areas in the northwest region and near Pati Point, the northernmost point in the east region. Large-fish biomass around Guam was low with a mean of 0.09 kg 100 m^{-2} (SE 0.03) among all areas surveyed around Guam during the 3 MARAMP survey periods. This large-fish-biomass value, which represents only 12% of the mean large-fish biomass observed for the Mariana Archipelago over the same time period, is the lowest value recorded for any island surveyed during the MARAMP.
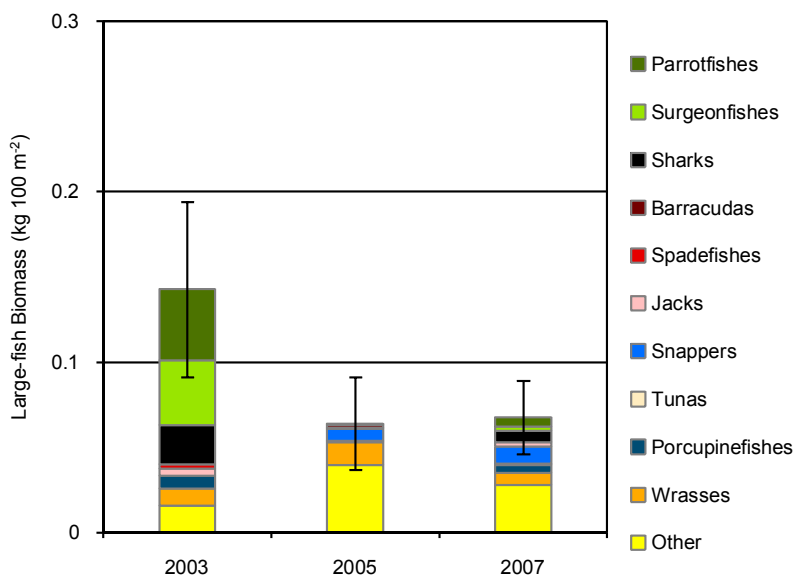

Figure 4.8.1d. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Total Fish Biomass and Species Richness

Total fish biomass for the 9 REA sites surveyed in forereef habitats around Guam during MARAMP 2003 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 2.66 kg 100 m^{-2} (SE 0.84). The highest biomass of 8.71 kg 100 m^{-2} was observed at GUA-05 in the northwest region, and the lowest biomass of 0.28 kg 100 m^{-2} was found at GUA-02 near Cetti Bay in the west region (Fig. 4.8.1e). Surgeonfishes accounted for the largest proportion (30%) or 0.10 kg 100 m^{-2} of total fish biomass around Guam, and the brown surgeonfish (*Acanthurus nigrofuscus*) was the most abundant species. Emperors (Lethrinidae), parrotfishes, and wrasses were also common, contributing 20%, 18%, and 8%, respectively, of total fish biomass around Guam. Although surveys suggest that large fishes were uncommon around Guam, the greatest number of fishes > 25 cm in TL observed around Guam occurred in the north and northwest regions. Juveniles were present but not abundant, and no reef sharks were observed during site-specific fish surveys.

Based on REA surveys conducted during MARAMP 2003, species richness around Guam was relatively low with a range of 13–26 species 100 m^{-2}. The lowest diversity was seen at GUA-02 in the west region, while the highest diversity was found at GUA-08 (Fig. 4.8.1e). Wrasses were observed in the greatest diversity with 22 species recorded in 2003. The fivestripe wrasse (*Thalassoma quinquevittatum*) was the most abundant wrasse species. Damselfishes (Pomacentridae) were the most abundant fish taxa overall, and the ocellate damselfish (*Pomacentrus vaiuli*) was the most common species with 7 individuals 100 m^{-2} recorded around Guam.
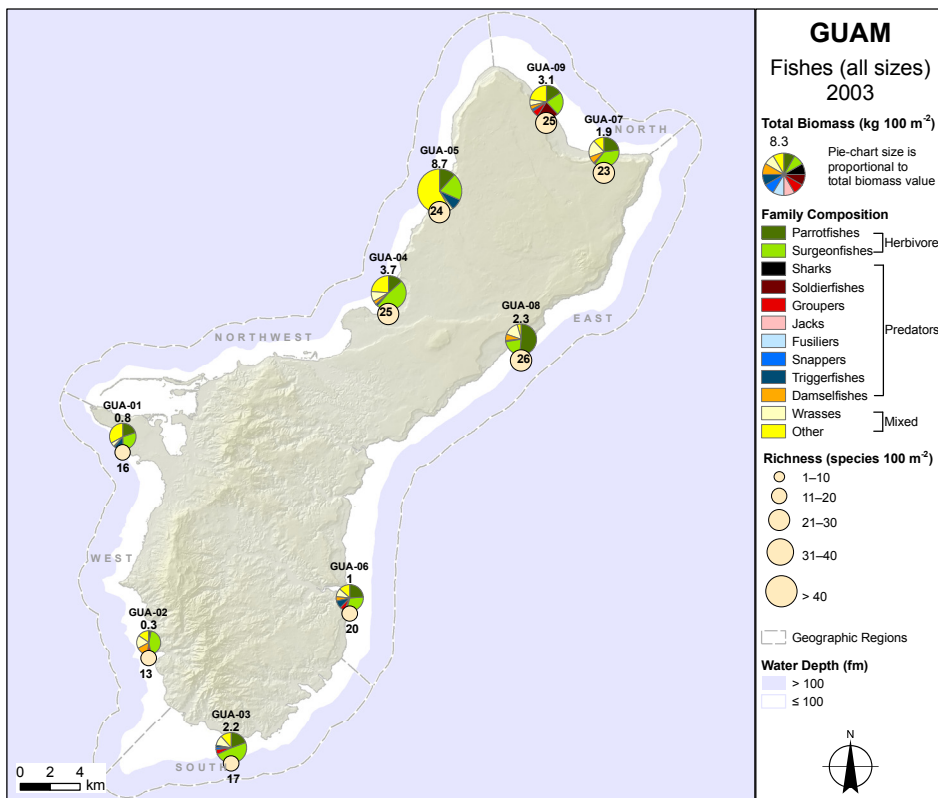
Figure 4.8.1e. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats around Guam during MARAMP 2003

Total fish biomass for the 9 REA sites surveyed in forereef habitats around Guam during MARAMP 2005 was very low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 1.40 kg 100 m^{-2} (SE 0.29). Biomass was slightly higher in the north and east regions as well as in the Tumon Bay and Pati Point Marine Preserves (Fig. 4.8.1f). Very few large and medium–large (> 20 cm in TL) fishes were recorded in the west region; however, they were observed in fair abundance in the north and northwest regions. Surgeonfishes accounted for the largest proportion (21%) or
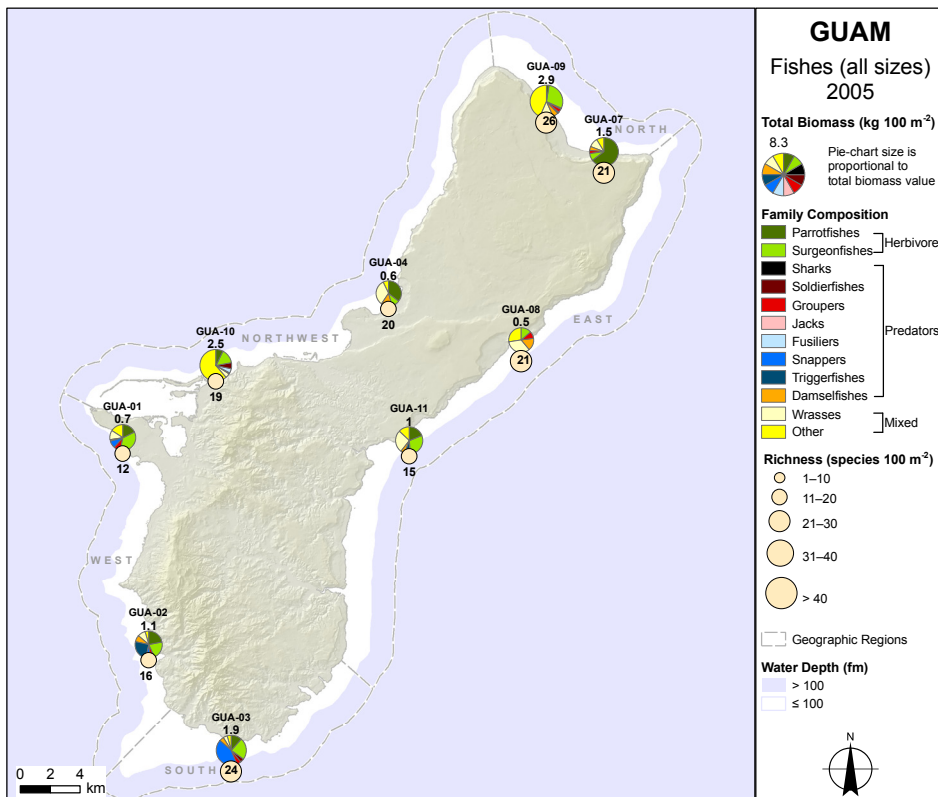
Figure 4.8.1f. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats around Guam during MARAMP 2005.

0.30 kg 100 m^{-2} of total fish biomass around Guam. Emperors, parrotfishes, and wrasses were also common, accounting for 17%, 17%, and 12% of total fish biomass around Guam. The abundance and diversity of damselfishes, wrasses, surgeon-fishes, and parrotfishes at GUA-03 in the south region may be related to this site's location inside the Achang Reef Flat Marine Preserve, which was established in 1997 through Guam Public Law 24-21.

Based on REA surveys conducted during MARAMP 2005, species richness around Guam was relatively low and similar to levels observed in 2003 with a range of 12–26 species 100 m^{-2}. The lowest diversity was seen at GUA-01 in the west region, while the highest diversity was found at GUA-09 near Jinapsan Point in the north region (Fig. 4.8.1f). Wrasses were observed in the greatest diversity with 20 species recorded around Guam in 2005. Consistent with values found in 2003, the fivestripe wrasse was the most abundant wrasse species. Also as in 2003, damselfishes were the most abundant fish taxa overall, and the ocellate damselfish was the most common species with 12 individuals 100 m^{-2} recorded around Guam.

Total fish biomass for the 10 REA sites surveyed in forereef habitats around Guam during MARAMP 2007 was low, compared to other sites in the Mariana Archipelago, with an overall sample mean of 2.53 kg 100 m^{-2} (SE 0.61). The highest biomass was seen in the northwest region at GUA-10 near Adelup Point and GUA-04 in Tumon Bay (Fig. 4.8.1g). Moray eels accounted for the largest proportion (19%) or 0.49 kg 100 m^{-2} of total fish biomass around Guam. Surgeonfishes, parrotfishes and wrasses were also common, contributing 16%, 15% and 11% of total fish biomass around Guam. A whitetip reef shark was recorded at GUA-07 in the north region.

Based on REA surveys conducted during MARAMP 2007, species richness around Guam was relatively low around this island with a range of 12–25 species 100 m^{-2}. The lowest diversity was seen at GUA-01 near Orote Peninsula in the west region (Fig. 4.8.1g). As in 2003 and 2005, wrasses were observed in the greatest diversity with 30 species recorded in 2007. Damselfishes again were the most abundant fish taxa overall, and the ocellate damselfish was the most common species with 21 individuals 100 m^{-2} recorded around Guam.

Figure 4.8.1g. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats around Guam during MARAMP 2007.
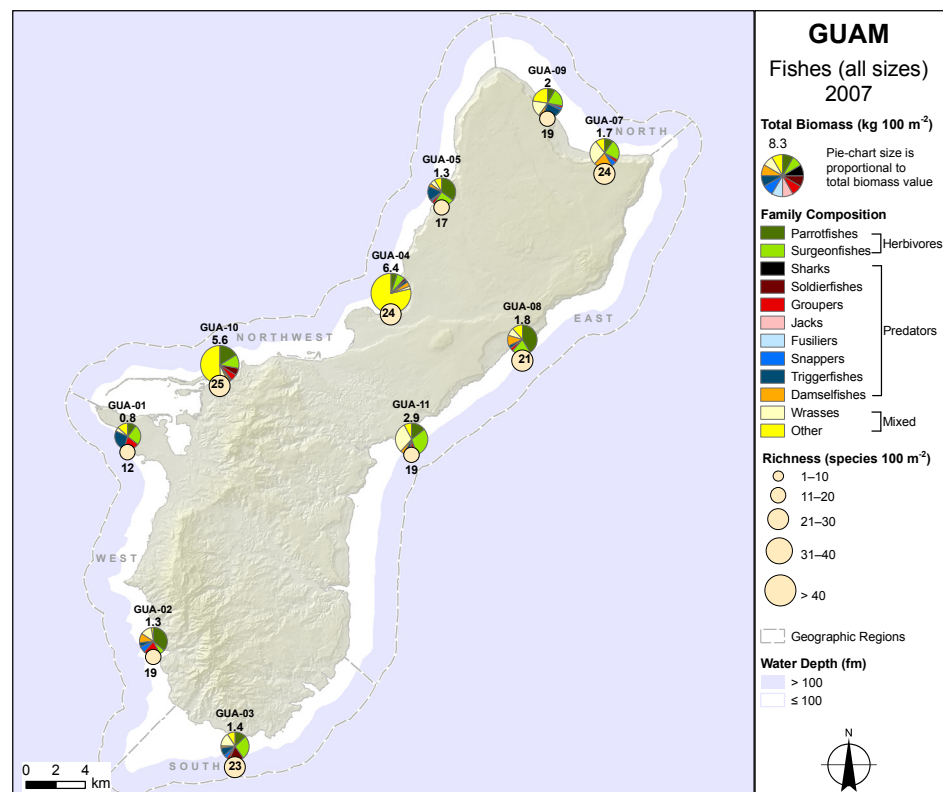
No persistent spatial patterns were observed for total fish biomass in forereef habitats around Guam between the 3 MARAMP survey periods. Biomass was slightly higher around the northern half of this island in 2003, but this pattern was less clear in following years. The majority of biomass recorded around Guam during the 3 survey years was composed of surgeonfishes, emperors, parrotfishes, and wrasses. Total fish biomass was consistently low between MARAMP survey years (Fig. 4.81h) with overall means for Guam between 1.40 kg 100 m^{-2} (SE 0.29) and 2.66 kg 100 m^{-2} (SE 0.84). Across the 3 MARAMP survey years combined, total fish biomass around Guam was the lowest in the Mariana Archipelago with an overall mean of 2.20 kg 100 m^{-2} (SE 0.40).

Species richness was relatively uniform around Guam in the 3 MARAMP survey years, except in the west region at GUA-01 near Orote Peninsula, where richness was consistently lower than values found at other sites. The average fish species richness around Guam was relatively low but consistent with the 20.2 species 100 m^{-2} (SE 0.5) observed during all REA fish surveys conducted during MARAMP 2003, 2005, and 2007. Wrasses were consistently represented with the most diversity with an average of 24 species observed across the survey years. Damselfishes were the most abundant taxa of fishes overall and dominated counts in each of the 3 survey periods.
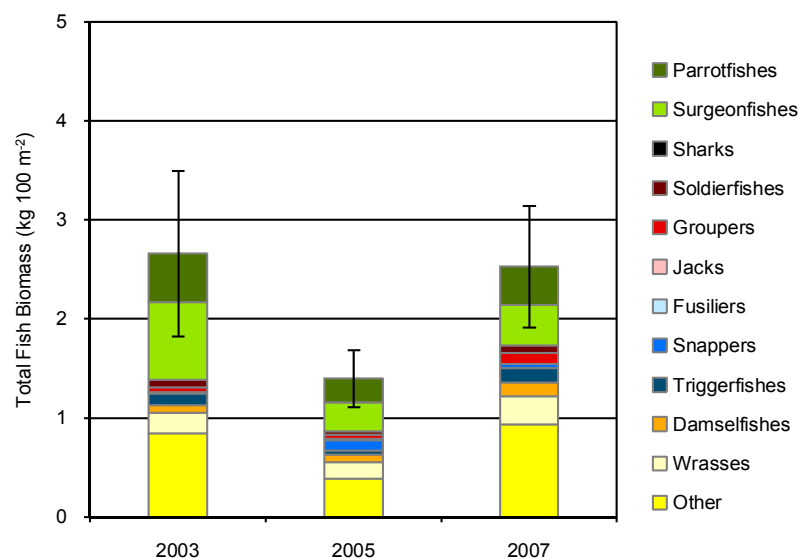
Figure 4.8.1h. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m^{-2}) from REA fish surveys of forereef habitats conducted around Guam during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

4.9   Marine Debris

4.9.1   Marine Debris Surveys

During MARAMP 2003, 14 sightings of derelict fishing gear and 21 sightings of other man-made objects were recorded in the 20 towed-diver surveys conducted on forereef habitats around the island of Guam (Fig. 4.9.1a). The highest number of sightings of derelict fishing gear was noted in the east region, while the highest number of man-made objects was observed in the west region, specifically near Agat Bay (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). Items near Agat Bay included 4 anchors, 1 pipe, and 1 steel cable. No additional descriptive information about the remaining sightings of derelict fishing gear and man-made objects was recorded during towed-diver surveys. No munitions or wrecks were identified.

During MARAMP 2005, 2 sightings of derelict fishing gear and 1 sighting of a man-made object were recorded in the 23 towed-diver surveys conducted on forereef habitats around Guam (Fig. 4.9.1b). These 2 sightings of derelict fishing gear included a single large trawl or seine net off Cocos Island in the south region, most of it located in a depth of 21–30 m and the rest extending to an undetermined depth. In shallower water upslope of this net, an area of damaged coral was noted, suggesting that this net had previously tumbled to its observed location. The other observed debris included a trawl net near Togcha Bay in the east region and an old automobile south of Adelup Point in the northwest region. No munitions or wrecks were identified.

Figure 4.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2003. Symbols indicate the presence of specific debris types.
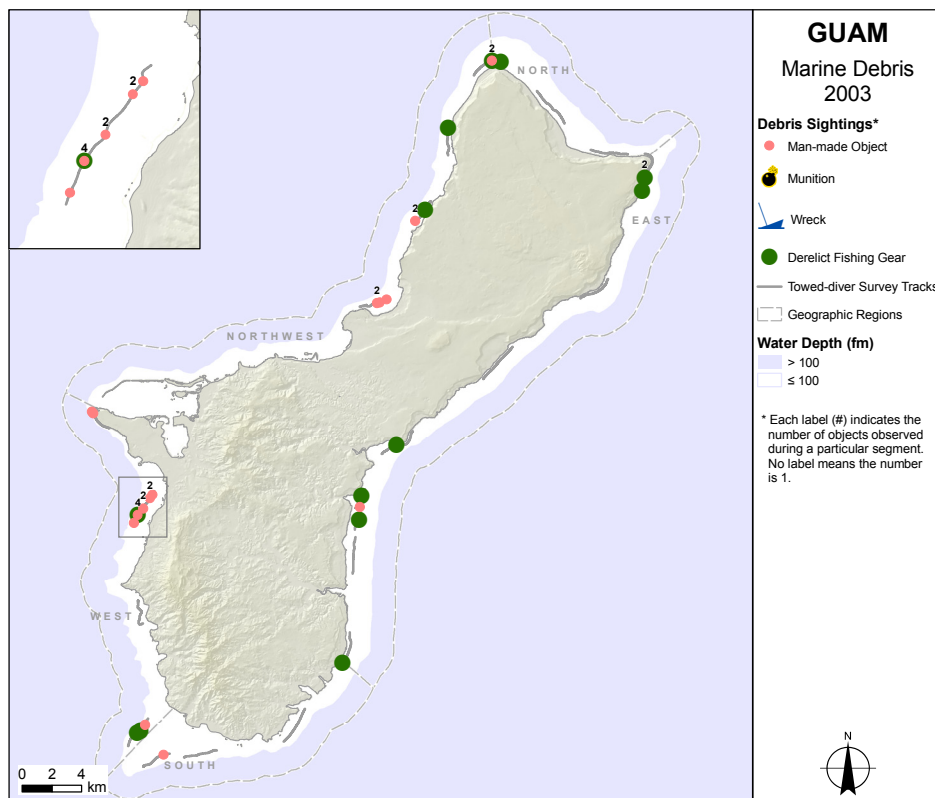
Figure 4.9.1b. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2005. Symbols indicate the presence of specific debris types.
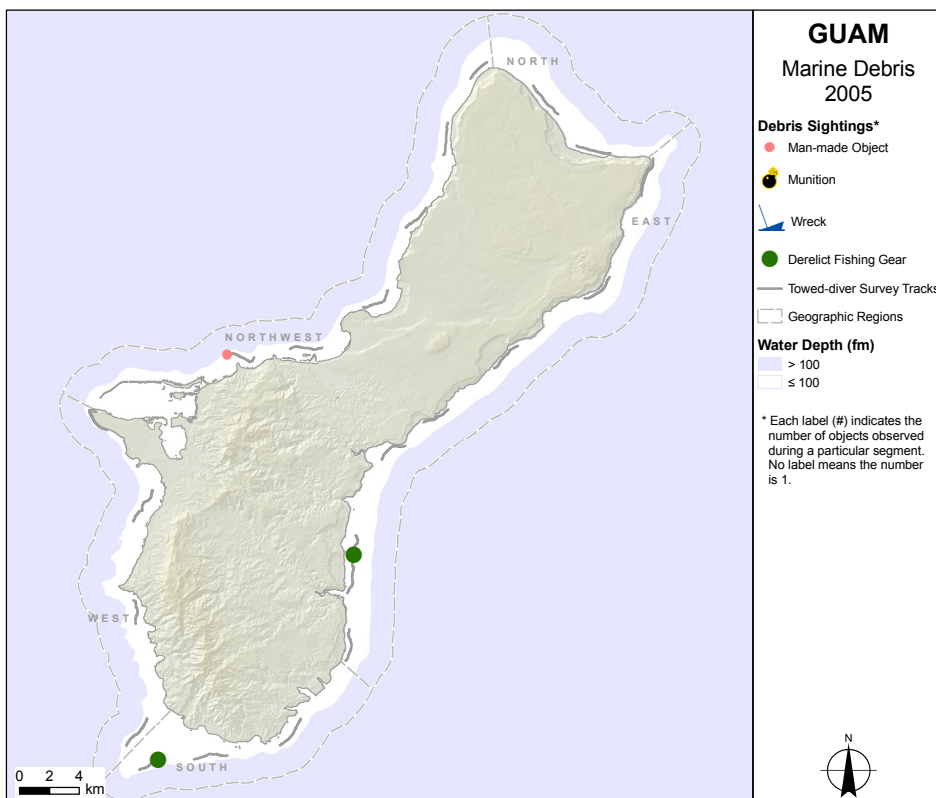

During MARAMP 2007, 3 sightings of derelict fishing gear and 4 sightings of other man-made objects were recorded in the 19 towed-diver surveys conducted on forereef habitats around Guam (Fig. 4.9.1c). The 3 sightings of derelict gear contained fishing lines and were noted 1 each in the northwest, west, and east regions. In each of the northwest and west regions, 2 man-made objects were recorded, with 3 of them noted as anchors. No munitions or wrecks were identified.
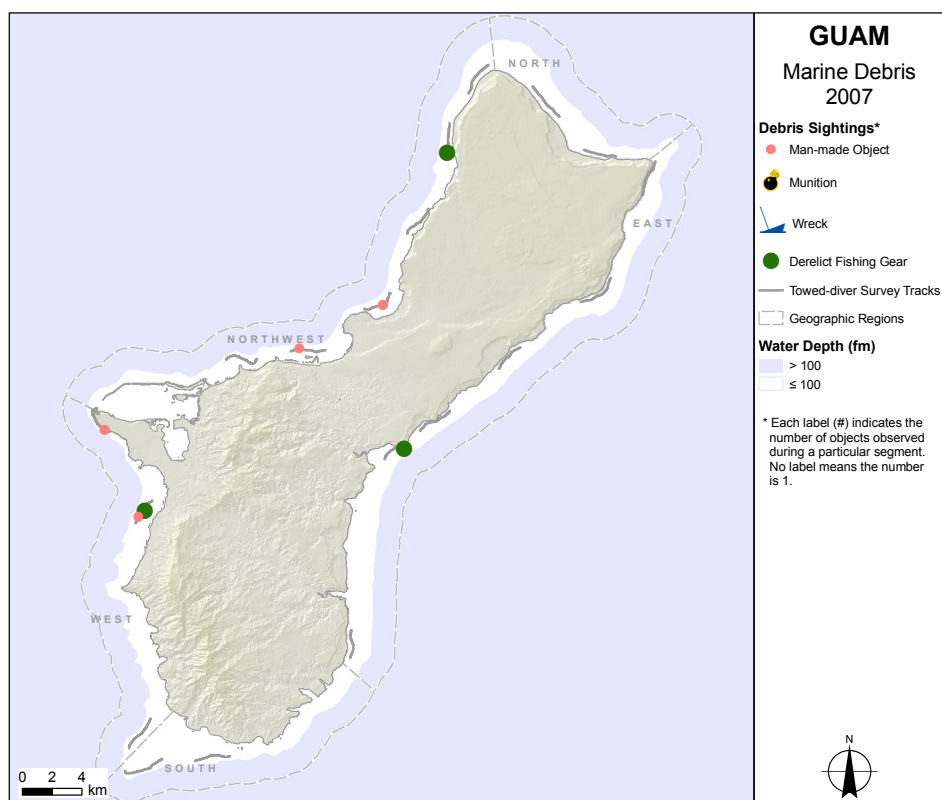
Figure 4.9.1c. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Guam during MARAMP 2007. Symbols indicate the presence of specific debris types.

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments.

4.10 Reefs and Banks

4.10.1 Introduction

In addition to forereef areas around the island of Guam, MARAMP surveys examined 3 nearby reefs: 11-mile Reef, Galvez Bank, and Santa Rosa Reef. All 3 reefs form a continuation of the southern Mariana Arc, and they are oriented in a northeast–southwest direction. The farthest from Guam, Santa Rosa Reef lies some 50 km south-southwest from the southern tip of Guam and is ~ 20 × 25 km in size. Galvez Bank at ~ 35 km in length is the largest of these 3 reefs and is located 22 km south-southwest of Guam. As its name suggests, 11-mile Reef is ~ 11 mi or 17 km southwest of Guam and is the smallest of the 3 banks with a length of ~ 15 km.

4.10.2 Survey Effort

Limited biological and physical observations of some of the conditions and processes influencing the coral reef ecosystems on Santa Rosa Reef have been collected since 2003 as part of the MARAMP. Benthic habitat mapping conducted on Santa Rosa Reef with multibeam sonar covered a total area of 164 km^2 in 2007. Ocean data platforms (ODPs) captured observations of temperature, salinity, and wave height from 2003 to 2007 (Table 4.10.2a). Limited information on the condition, abundance, diversity, and distribution of some biological communities on Santa Rosa Reef was collected using REA, towed-diver, and TOAD surveys in 2003 and 2005 (Table 4.10.2b).

In addition, on 11-mile Reef and Galvez Bank during MARAMP 2003, TOAD surveys documented estimates of sand cover, live-hard-coral cover, and habitat complexity (Table 4.10.2c).

The spatial extent and timeframe of towed-diver surveys are discussed in this section. Figure 4.10.2a displays the locations of the REA, towed-diver, and TOAD surveys conducted on these 3 banks. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

Figure 4.10.2a. Locations of REA, towed-diver, and TOAD surveys conducted on banks adjacent to Guam during MARAMP 2003 and 2005.
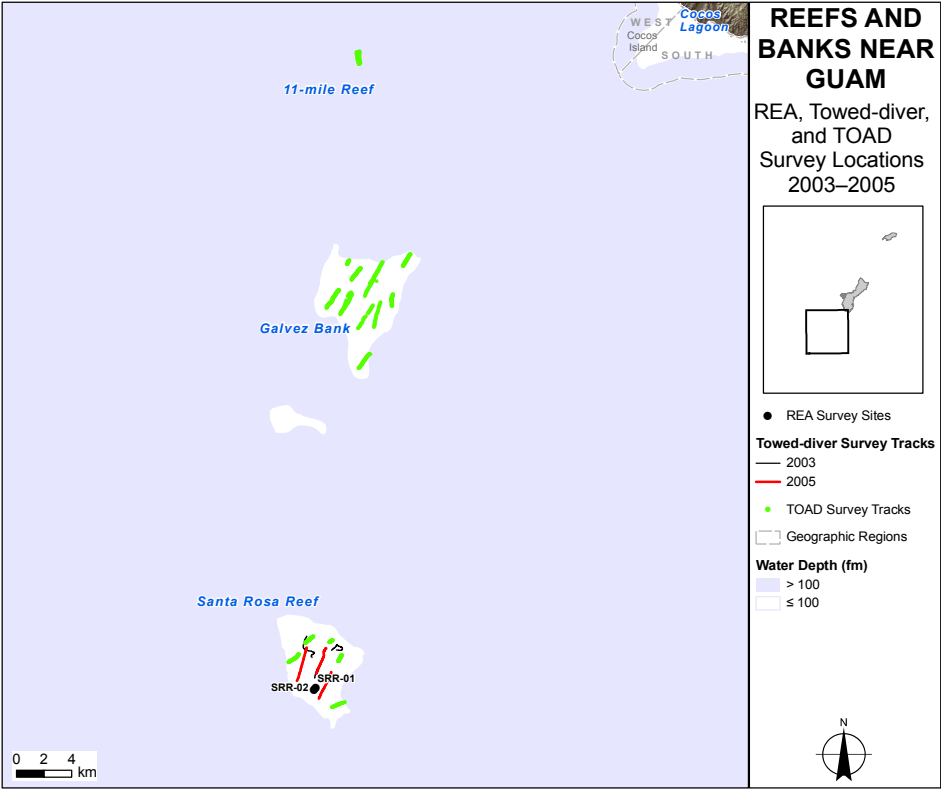
Table 4.10.2a. Numbers of ocean data platforms (ODPs) deployed on Santa Rosa Reef during MARAMP 2003, 2005, and 2007.

Observation Type	Year						Lost
Instruments	**2003**	**2005**		**2007**		**2009**	
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
ODP	1	1	1	1	–	–	–

Table 4.10.2b. Numbers, mean depths (m), total areas (ha), and total lengths (km) of REA, towed-diver, and TOAD surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. REA survey information is provided for both fish and benthic surveys.

Survey Type	Survey Detail	Year	
REA		**2003**	**2005**
Fish	Number of Surveys	2	2
	Mean Depth (m)	12.5 (SD 0.7)	12.5 (SD 0.7)
Benthic	Number of Surveys	2	2
	Mean Depth (m)	12.5 (SD 0.7)	12.5 (SD 0.7)
Towed Diver		**2003**	**2005**
	Number of Surveys	3	3
	Total Survey Area (ha)	5.9	6.9
	Mean Depth (m)	16.1 (SD 3.9)	15.1 (SD 3.7)
TOAD		**2003**	
	Number of Surveys	5	
	Total Length (km)	3.61	

Table 4.10.2c. Numbers and total lengths (km) of TOAD surveys conducted on 11-mile Reef and Galvez Bank during MARAMP 2003.

Survey Type	Survey Detail	Year
TOAD		**2003**
11-mile Reef	Number of Surveys	2
	Total Length (km)	1.85
Galvez Bank	Number of Surveys	11
	Total Length (km)	17.43

GUAM

Towed-diver Surveys: Depths

Figures 4.10.2b and c illustrate the locations and depths of towed-diver-survey tracks on Santa Rosa Reef and should be referenced when further examining results of towed-diver surveys from MARAMP 2003 and 2005.

During MARAMP 2003, 3 towed-diver surveys were conducted on Santa Rosa Reef. The mean depth of all survey segments was 16.1 m (SD 3.9), and the mean depths of individual surveys ranged from 11.6 m (SD 0.7) to 18.5 m (SD 3.2).

During MARAMP 2005, 3 towed-diver surveys were conducted on Santa Rosa Reef. The mean depth of all survey segments was 15.1 m (SD 3.7), and the mean depths of individual surveys ranged from 12.2 m (SD 1) to 19.2 m (SD 3.2).
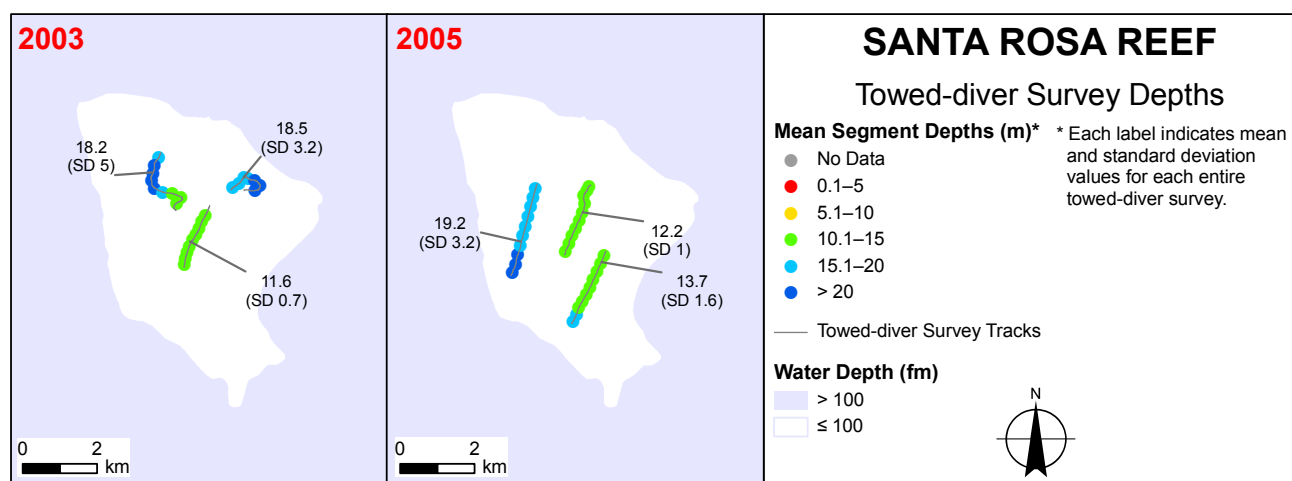
Figure 4.10.2b. Depths and tracks of towed-diver surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Towed-diver survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.
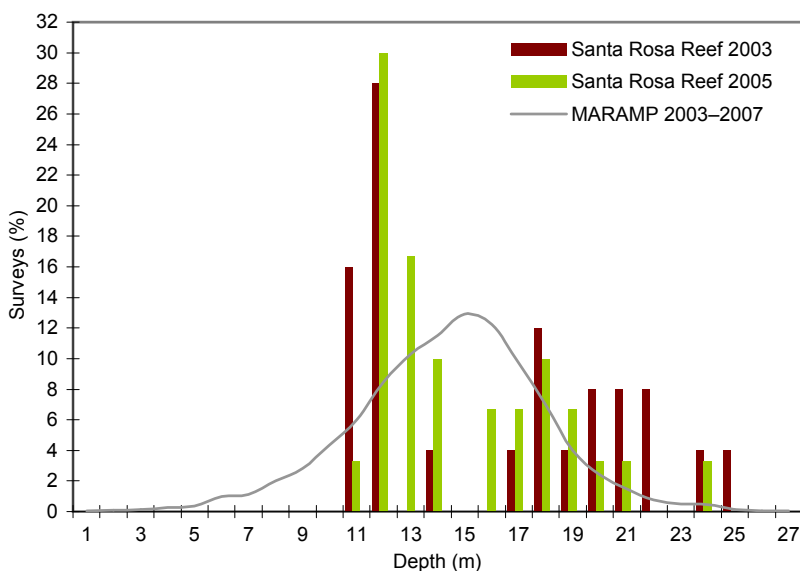
Figure 4.10.2c. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded are excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago from 2003 to 2007.

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4.10.3 Benthic Habitat Mapping and Characterization

Acoustic Mapping

In addition to the benthic habitat mapping and characterization of nearshore waters around Guam, limited surveys were undertaken on Santa Rosa Reef, Galvez Bank, and 11-mile Reef, using acoustic multibeam sonar, underwater video and still imagery, and towed-diver surveys during MARAMP 2003 and 2005. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted at depths of ~ 10–88 m.

Time constraints meant a full multibeam survey on these reefs was not possible; however, one swath was obtained during transit, providing data along the eastern edge of these 3 reefs at depths of ~ 150–1800 m. For a more complete picture of the topography of these reefs, these limited multibeam bathymetry data are presented over a bathymetry grid with a 30-arc-second (~ 900-m) resolution and based on a satellite-gravity model calibrated with depth soundings (Becker et al. 2009; Fig. 4.10.3a). No backscatter data are presented here because of the extremely limited coverage.

Located ~ 15 km west of Guam's Cocos Lagoon, 11-mile Reef is separated from Guam by a deep (~ 1.7 km) channel. Galvez Bank is joined to the tip of Cocos Lagoon by a ridge that is ~ 15 km long and ~ 1 km deep, and this bank also appears from the modeled bathymetry data (Becker et al. 2009) to be nearly continuous with Santa Rosa Reef to the south.

Figure 4.10.3a. Gridded multibeam bathymetry (grid cell size: 60 m) collected by CRED during MARAMP 2007 at depths of 5–2500 m using a 30-kHz Kongsberg EM 300 sonar are shown in the area outlined in black. Shown elsewhere are modeled bathymetry data (grid cell size: 30 arc-second or ~ 900 m; Becker et al. 2009).
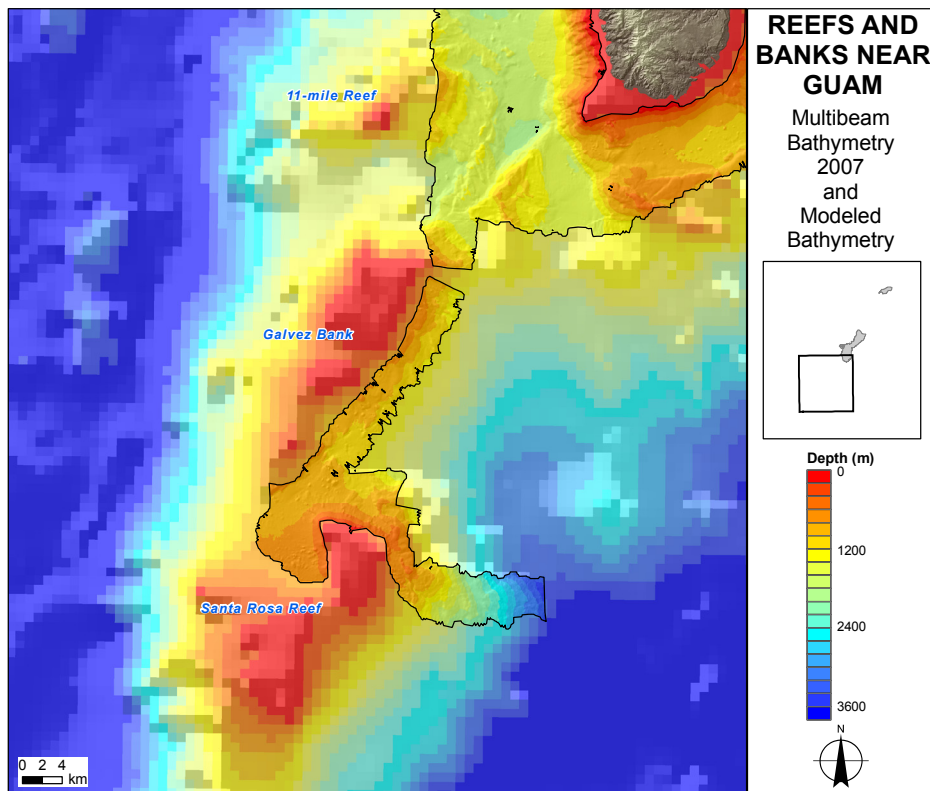
Optical Validation

During MARAMP 2003, 5 TOAD optical-validation surveys were conducted on Santa Rosa Reef at depths of 50–100 m, 11 TOAD surveys were completed on Galvez Bank at depths of ~ 20–88 m and 2 TOAD surveys were completed on 11-mile Reef at depths of < 70 m (Fig. 4.10.2a). Subsequent analysis of the acquired video provided estimates of the percentages of both sand cover and live-hard-coral cover.
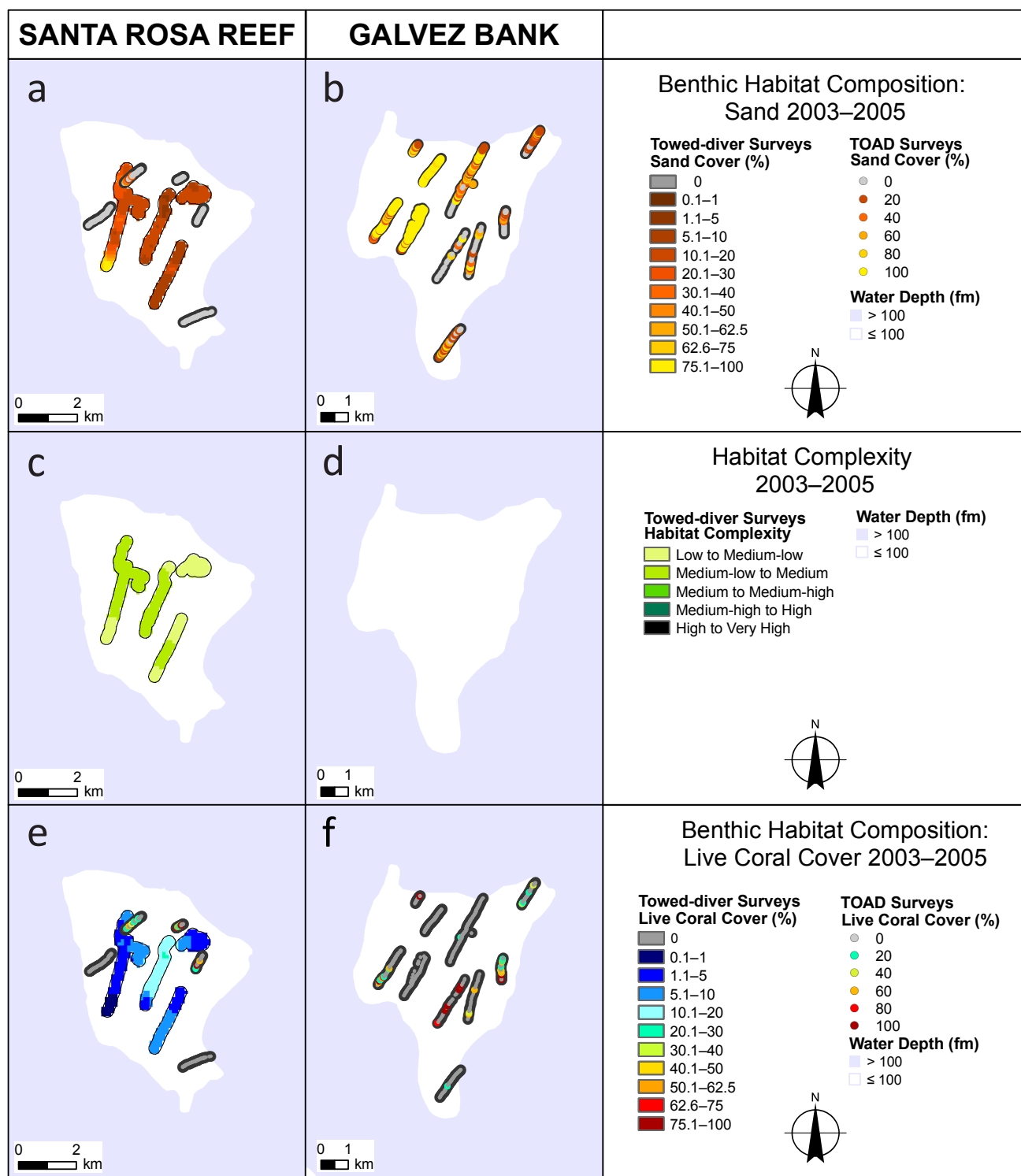
During MARAMP 2003 and 2005, 3 towed-diver optical-validation surveys each were conducted on Santa Rosa Reef, covering a distance of 12 km at depths of 11–25 m (Fig. 4.10.2a). At 5-min intervals within each survey, divers recorded percentages of sand cover and live coral cover and habitat complexity using a 6-level categorical scale from low to very high.

Habitat Characterization

Optical-validation surveys conducted on Santa Rosa Reef revealed that its reef top had predominantly hard substrate, generally with sand cover of < 30% observed during towed-diver surveys and in TOAD videos (Fig. 4.10.3b[a]). A small number of areas with higher sand cover were found, including an area on the western part of this reef, where towed-diver surveys recorded sand cover of 75.1%–100%. Habitat complexity observed by towed divers in all areas surveyed ranged from low to medium (Fig. 4.10.3b[c]). Live coral cover, recorded during both towed-diver and TOAD surveys, was low (Fig. 4.10.3b[e]). Coral cover was < 20% in all areas surveyed, except for a few, very small areas during a single towed-diver survey. Similarly, only a small number of video frames from TOAD footage collected at depths of 15–22 m had live coral cover of 20.1%–100%.

On Galvez Bank, 11 TOAD surveys were conducted at depths of 25–83 m. Survey results for the western part of this bank at depths of 27–83 m revealed a predominantly sandy substrate (Fig. 4.10.3b[b]). A more mixed substrate for the eastern part of Galvez Bank was suggested by analysis of TOAD video footage. Live corals were observed in a small number of analyzed frames, with 9 video frames from TOAD footage collected at depths of 27–66 m revealing substrate with very high coral cover (Fig. 4.10.3b[f]).

On 11-mile Reef, 2 TOAD surveys were conducted at depths of < 70 m. Because of this limited number of optical-validation surveys, results from these 2 surveys are not presented on Figure 4.10.3b. Analysis of TOAD video footage revealed that the substrate on this reef was predominantly hard (66% of analyzed video frames). Only 4 (8%) of analyzed video frames from TOAD footage had live coral cover of 40%–80%.

SANTA ROSA REEF	GALVEZ BANK	

a / **b** — Benthic Habitat Composition: Sand 2003–2005

Towed-diver Surveys Sand Cover (%)
- 0
- 0.1–1
- 1.1–5
- 5.1–10
- 10.1–20
- 20.1–30
- 30.1–40
- 40.1–50
- 50.1–62.5
- 62.6–75
- 75.1–100

TOAD Surveys Sand Cover (%)
- 0
- 20
- 40
- 60
- 80
- 100

Water Depth (fm)
- > 100
- ≤ 100

c / **d** — Habitat Complexity 2003–2005

Towed-diver Surveys Habitat Complexity
- Low to Medium-low
- Medium-low to Medium
- Medium to Medium-high
- Medium-high to High
- High to Very High

Water Depth (fm)
- > 100
- ≤ 100

e / **f** — Benthic Habitat Composition: Live Coral Cover 2003–2005

Towed-diver Surveys Live Coral Cover (%)
- 0
- 0.1–1
- 1.1–5
- 5.1–10
- 10.1–20
- 20.1–30
- 30.1–40
- 40.1–50
- 50.1–62.5
- 62.6–75
- 75.1–100

TOAD Surveys Live Coral Cover (%)
- 0
- 20
- 40
- 60
- 80
- 100

Water Depth (fm)
- > 100
- ≤ 100

Figure 4.10.3b. Observations of (a, b) sand cover (%), (c, d) benthic habitat complexity, and (e, f) cover (%) of live hard corals from towed-diver surveys conducted and analysis of TOAD videos collected on Santa Rosa Reef and Galvez Bank during MARAMP 2003 and 2005.

4.10.4 Oceanography and Water Quality

Time-series Observations

One ocean data platform (ODP) mooring site was established at a depth of 20 m on Santa Rosa Reef. Temperature and salinity data from this ODP site show primarily seasonal oscillations, although intraseasonal–interannual variability is discernable (Fig. 4.10.4a). Seasonal temperature fluctuations were characterized by temperatures of ~ 30°C during the months of June–October and ~ 27.5°C during the months of January–March. Intraseasonal temperature variability was observed during summer 2004 when temperatures varied 0.5°C–1°C every few weeks for a 5-month period. Similar oscillations were observed in summer 2006, although this period was dominated by a major warming event in September 2006 that surpassed the bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean. Salinity values are generally negatively correlated with temperature; decreases in salinity co-occur with increases in temperature. However, this overall time series for Santa Rosa Reef shows less seasonal periodicity in salinity values than in temperature values from ODP data.
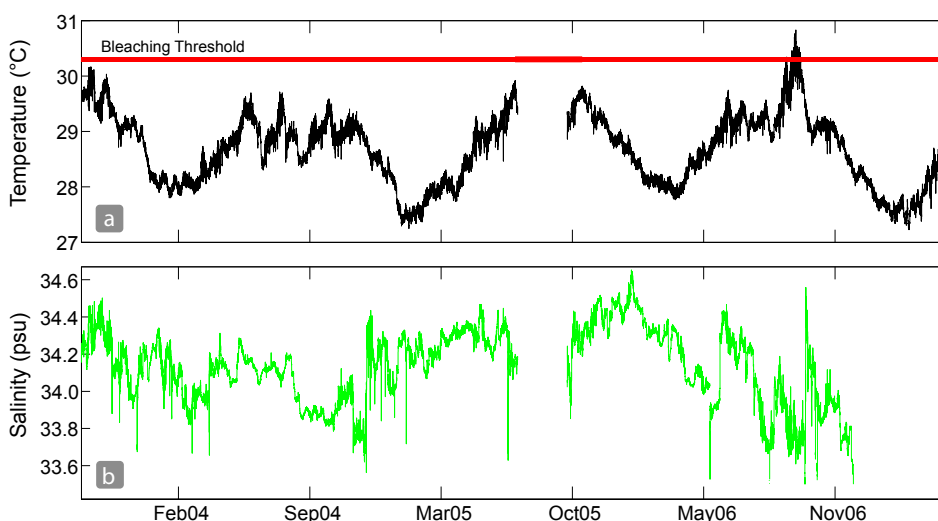
Figure 4.10.4a. Time-series observations of (*a*) temperature and (*b*) salinity over the period between September 2003 and June 2007 collected from ODPs deployed on Santa Rosa Reef at a 20-m depth. The horizontal red line indicates the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

Wave heights were measured on Santa Rosa Reef from September 2003 to May 2007. Wave heights were generally dominated by a seasonal pattern, with the highest ambient wave heights occurring during winter and the lowest during summer. Superimposed on these seasonal fluctuations were episodic wave events that were characterized by brief periods of high (> 3 m) wave heights—which are typically associated with the typhoon season of August–December but are also observed during other time periods. Wave conditions can be highly variable from year to year. Wave conditions were characterized in 2004 by a few large (> 5 m) wave events but in 2006 by fewer and less energetic episodic events; yet, wave conditions in 2006 had higher ambient wave heights through the winter than they had in the previous 2 years (Fig. 4.10.4b).
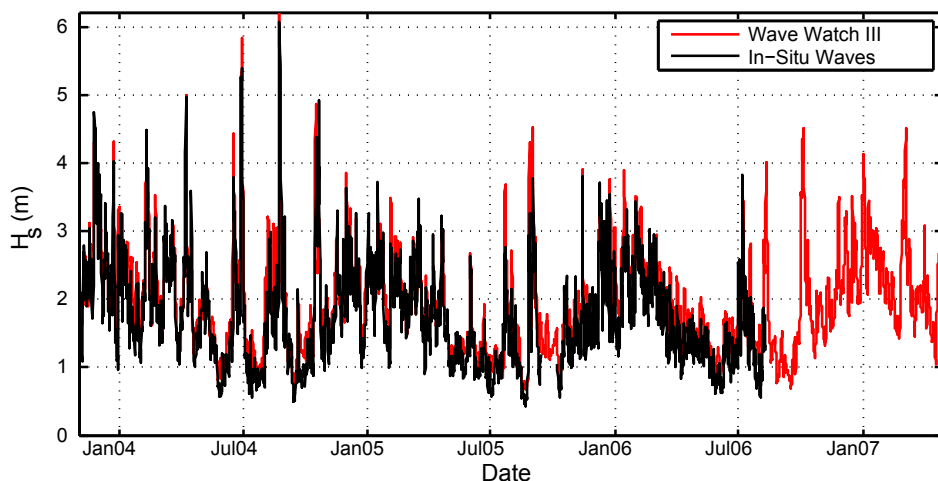
Figure 4.10.4b. Time-series observations of in situ (black line) and modeled (red line) significant wave height during the period between September 2003 and May 2007 collected from ODPs moored on Santa Rosa Reef at a depth of 20 m. Modeled wave data is derived from the NOAA Wave Watch III wave model.
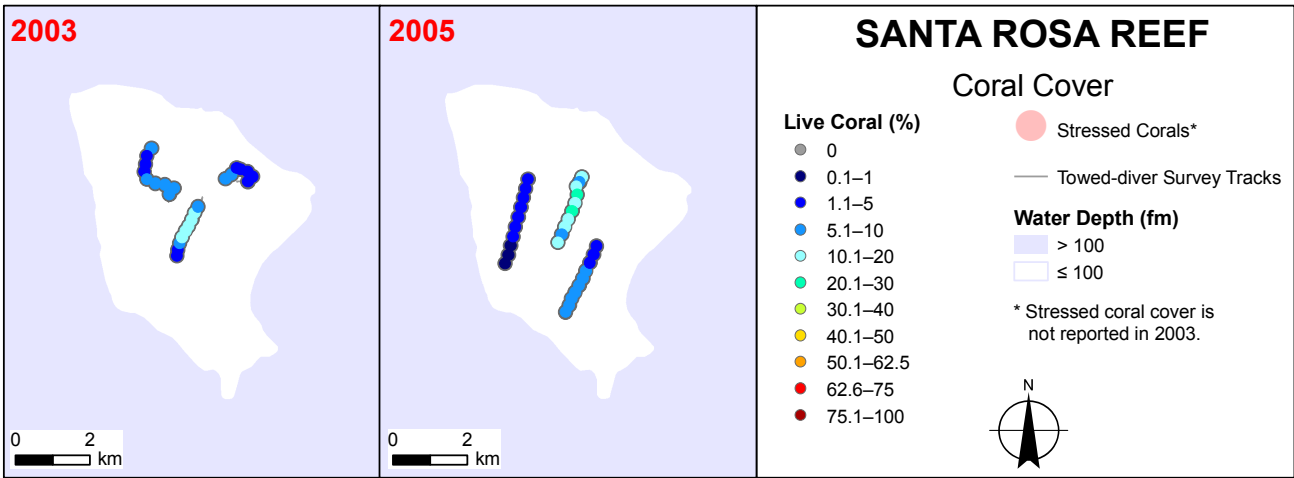
4.10.5 Coral Surveys
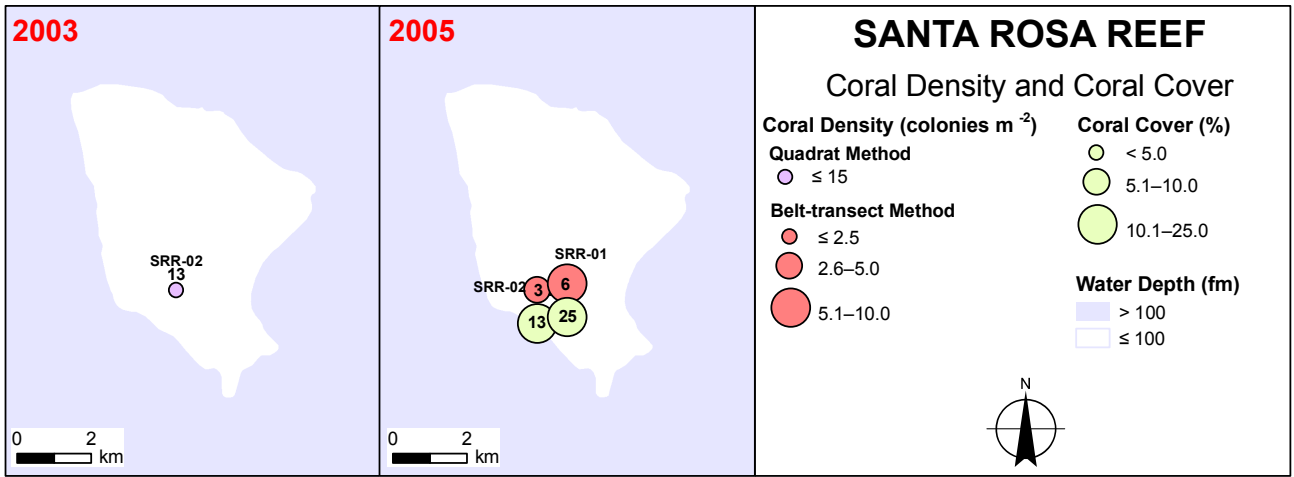
Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on Santa Rosa Reef was 7% (SE 0.9). The highest mean coral cover was observed in the center of Santa Rosa Reef with a mean of 15% for 6 survey segments (Fig. 4.10.5a, left panel). All other segments recorded coral cover ≤ 10%.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on Santa Rosa Reef was 8% (SE 1.2). The highest coral cover was observed in the center of Santa Rosa Reef with a mean of 17.5% for 8 segments (Fig. 4.10.5a, right panel). All other segments recorded coral cover ≤ 10%, with the lowest coral cover of 0.1%–1% noted for 3 segments along the southwestern area of Santa Rosa Reef.

Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that was fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5: "Corals and Coral Disease"). Overall, 0.3% (SE 0.1) of observed coral cover appeared stressed on Santa Rosa Reef.

Figure 4.10.5a. Cover (%) observations of live hard corals from towed-diver benthic surveys conducted at Santa Rosa Reef during MARAMP 2003 and 2005. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). Stressed-coral cover was measured as a percentage of overall coral cover in 2005; no pink symbols appear in the 2005 panel because no areas had stressed-coral cover > 10%.

Figure 4.10.5b. Cover (%) and colony-density (colonies m⁻²) observations of live hard corals from REA benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Values are provided within each symbol.
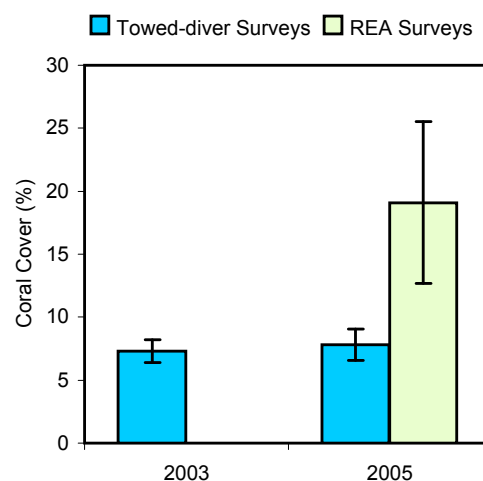
During MARAMP 2003, 1 REA benthic survey using the quadrat method on Santa Rosa Reef at SRR-02 documented 47 coral colonies within a survey area of 3.75 m². Site-specific colony density was 12.5 colonies m-2 (Fig. 4.10.5b, left panel).

During MARAMP 2005, 2 REA benthic surveys using the belt-transect method on Santa Rosa Reef documented 843 coral colonies within a total survey area of 200 m². Site-specific colony density was 2.8 colonies m^{-2} at SRR-02 and 5.7 colonies m^{-2} at SRR-01 (Fig. 4.10.5b, right panel).

Site-specific estimates of live-hard-coral cover, from MARAMP 2005 REA benthic surveys conducted using the line-point-intercept method on Santa Rosa Reef, were 12.7% at SRR-02 and 25.5% at SRR-01 (Fig. 4.10.5b, right panel).

Mean live-coral-cover estimates from towed-diver surveys were similar during both MARAMP survey years with 7% in 2003 and 8% in 2005 (Fig. 4.10.5c). In both years, peak coral cover was noted for the central portion of Santa Rosa Reef, and the lowest value of coral cover for this reef were recorded towards the perimeter. In 2005, the single year in which REA surveys for coral cover were conducted on this reef, mean coral cover for the 2 sites surveyed was 19.1%. Estimates of live coral cover from REA surveys generally exceed estimates from towed-diver surveys because REA surveys target hard-bottom communities whereas towed-diver surveys include both hard- and soft-bottom substrates.

Coral-colony density from REA surveys at SRR-02 was substantially lower in 2005 than in 2003 (Fig. 4.10.5d). However, this apparent decline is likely an artifact of the use of different methods to assess colony density during the 2 MARAMP survey years. The placement of quadrats used in 2003 was highly biased towards surveying hard-bottom substrate where corals were present, whereas the belt-transect method used in 2005 assessed benthos that fell within the transect belt regardless of the nature of the substrate. The considerable difference in apparent colony density at SRR-02, with 12.5 colonies m^{-2} in 2003 and 2.8 colonies m^{-2} 2005, strengthens the supposition that the quadrat method yielded higher density values than did the belt-transect method.

Figure 4.10.5c. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. No REA surveys using the line-point-intercept method were conducted on this reef in 2003. Error bars indicate standard error (± 1 SE) of the mean.
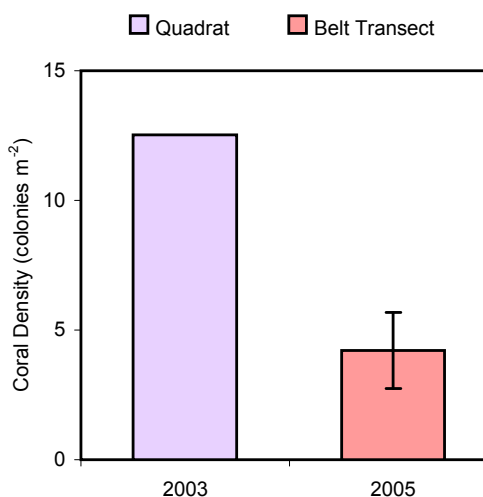
Figure 4.10.5d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. The quadrat method was used in 2003 at the single site surveyed to measure colony density, but in 2005 the belt-transect method was used. Error bars indicate standard error (± 1 SE) of the mean.

Coral Generic Richness and Relative Abundance

One REA benthic survey was conducted using the quadrat method during MARAMP 2003 to determine generic richness and relative abundance at Santa Rosa Reef. At least 9 coral genera were observed (Fig. 4.10.5e, left panel). *Favia*, *Leptastrea*, and *Porites* were the most numerically abundant genera, accounting for 36.2%, 17%, and 17% of the total number of colonies enumerated at SRR-02. All other genera individually accounted for < 10% of the total number of observed colonies.

Two REA benthic surveys were conducted using the belt-transect method during MARAMP 2005 to determine generic richness and relative abundance on Santa Rosa Reef. At least 16 coral genera were observed. Generic richness was 13 at SRR-02 and 15 at SRR-01 (Fig. 4.10.5e, right panel). *Favia*, *Pocillopora*, *Porites*, and *Leptastrea* were the most numerically abundant genera, accounting for 22.8%, 17.2%, 13.8%, and 11.9% of the total number of colonies enumerated on this reef during MARAMP 2005. All other genera individually accounted for < 10% of the total number of observed colonies. *Porites*, *Pocillopora*, and *Favia* dominated the coral fauna at SRR-01, accounting for 20.2%, 18.8%, and 16.9% of the total number of observed colonies, while *Favia*, *Leptastrea*, and *Pocillopora* dominated at SRR-02, accounting for 28.7%, 19.6%, and 15.6% of the total number of observed colonies.
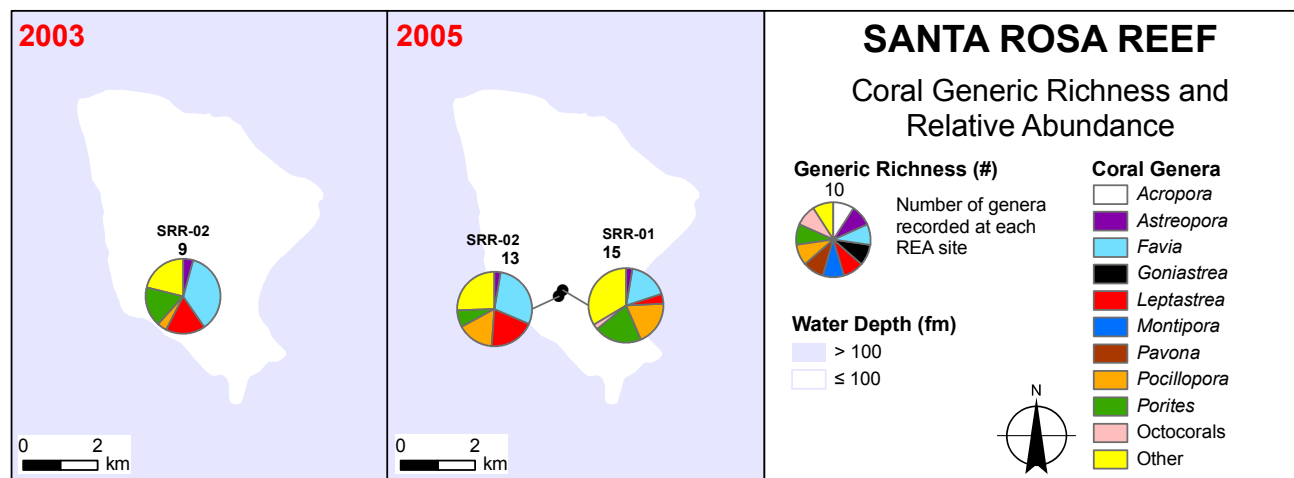
Figure 4.10.5e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. The pie charts indicate percentages of relative abundance of key coral genera.
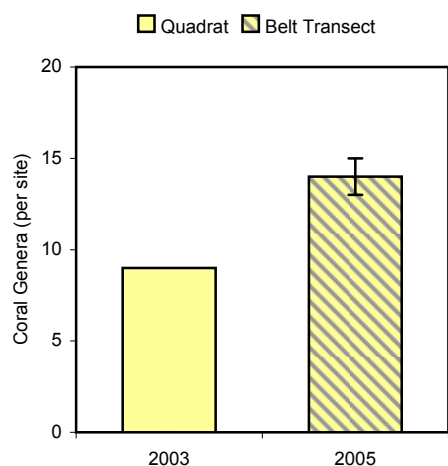
Figure 4.10.5f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. The quadrat method was used at a single site in 2003, and the belt-transect method was used at 2 sites in 2005. Error bars indicate standard error (± 1 SE) of the mean.

At least 17 coral genera were observed during the 2 MARAMP survey years, with a higher number of genera recorded in 2005 than in 2003 (Fig. 4.10.5f). Six genera not recorded in 2003 were observed in 2005, because in 2005 an additional site was surveyed and a larger area of 100 m^2 was surveyed at each site, versus the 3.75 m^2 surveyed per site in 2003. Also, the only octocoral genus assessed in 2003 was *Heliopora*, but all octocoral genera were assessed in 2005. *Favia*, *Porites*, and *Leptastrea* were important components of the coral fauna, accounting for > 10% of the total number of colonies enumerated on this reef in both years. *Favia* was the most abundant taxon in 2003 and 2005, accounting for 36.2% and 22.8% of the total number of observed colonies. *Pocillopora* was an important component of the coral fauna in 2005 but accounted for < 5% of the total number of observed colonies at SRR-02, the single site surveyed in 2003.

Coral Size-class Distribution

During MARAMP 2003, a coral size-class distribution from the single REA benthic survey conducted using the quadrat method showed the majority (93.6%) of corals had maximum diameters < 5 cm (Fig. 4.10.5g). The remaining corals belonged to the next-largest size class (6–10 cm); no coral colonies > 10 cm were observed.

During MARAMP 2005, coral size-class distributions from REA benthic surveys conducted using the belt-transect method showed the majority (57.3%) of corals had maximum diameters < 10 cm (Fig. 4.10.5g). The next 3 size classes (11–20, 21–40, and 41–80) accounted for 31.8%, 9.1%, and 1.3% of colonies recorded.

As discussed in greater detail in the coral-size-class-distribution section for Guam, these results reflect the respective biases of each method in capturing very small (≤ 5 cm) colonies (quadrat method) or large colonies (belt-transect method). Comparing size-class data between MARAMP survey years when different methods were used is inappropriate. The difference in size-class distribution at SRR-02 in 2003 and 2005 does not reflect substantial growth by the majority of colonies at that site, since *Favia*, *Porites*, and *Leptastrea*, the dominant corals at SRR-02, do not grow fast enough to produce such a radical change in distribution over a 2-year period. Instead, the change in the size-class distribution can be attributed to the use of different methods and the varied placement of quadrats and transect belts. For more on these survey methods, see "Chapter 2: "Methods and Operational Background", Section 2.4.5: "Corals and Coral Disease."
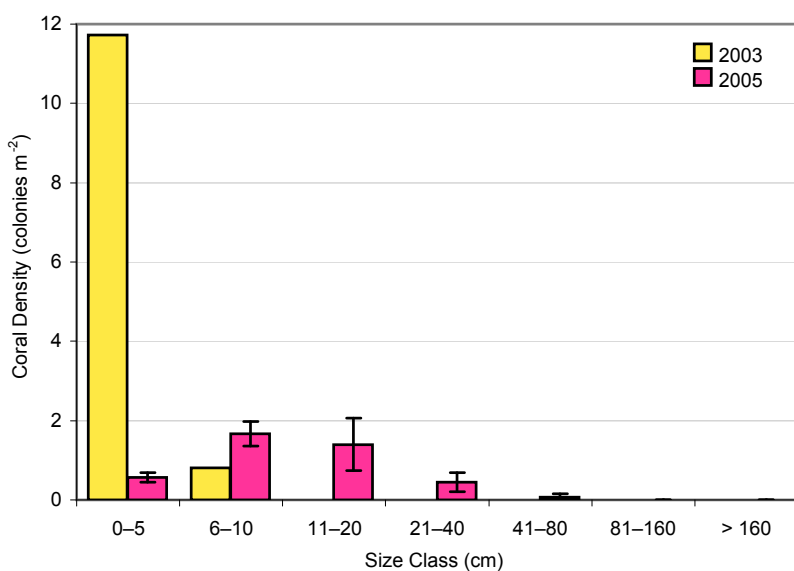
Figure 4.10.5g. Mean coral-colony densities (colonies m^{-2}) by size class from REA benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. The quadrat method was used in 2003 to size corals, and the belt-transect method was used in 2005. Error bars indicate standard error (± 1 SE) of the mean.

4.10.6 Algal Surveys

Algal Cover

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on Santa Rosa Reef was 42% (SE 4.6). The 3 surveys on this reef recorded macroalgal-cover values of 5.4%, 52.2%, and 58.8% (Fig. 4.10.6a, top left panel). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. Results from the first 2 surveys suggest mostly spur-and-groove habitat of medium-low complexity. The third survey primarily reported low complexity pavement in addition to limited spur-and-groove formations.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on Santa Rosa Reef was 71% (SE 3.1). The 3 surveys on this reef recorded macroalgal-cover values of 74.4%, 78.1%, and 59.1% (Fig. 4.10.6a, bottom left panel). Medium complexity substrates were the most common habitat encountered.

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on Santa Rosa Reef was 7% (SE 1.1). The 3 surveys conducted on this reef had mean cover values for crustose coralline red algae of 0%, 9.2%, and 10% (Fig. 4.10.6.a, top right panel).

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on Santa Rosa Reef was 0.5% (SE 0.1). The 3 surveys conducted on this reef had mean cover values for crustose coralline red algae of 0%, 0.5%, and 1.1% (Fig. 4.10.6a, bottom right panel).
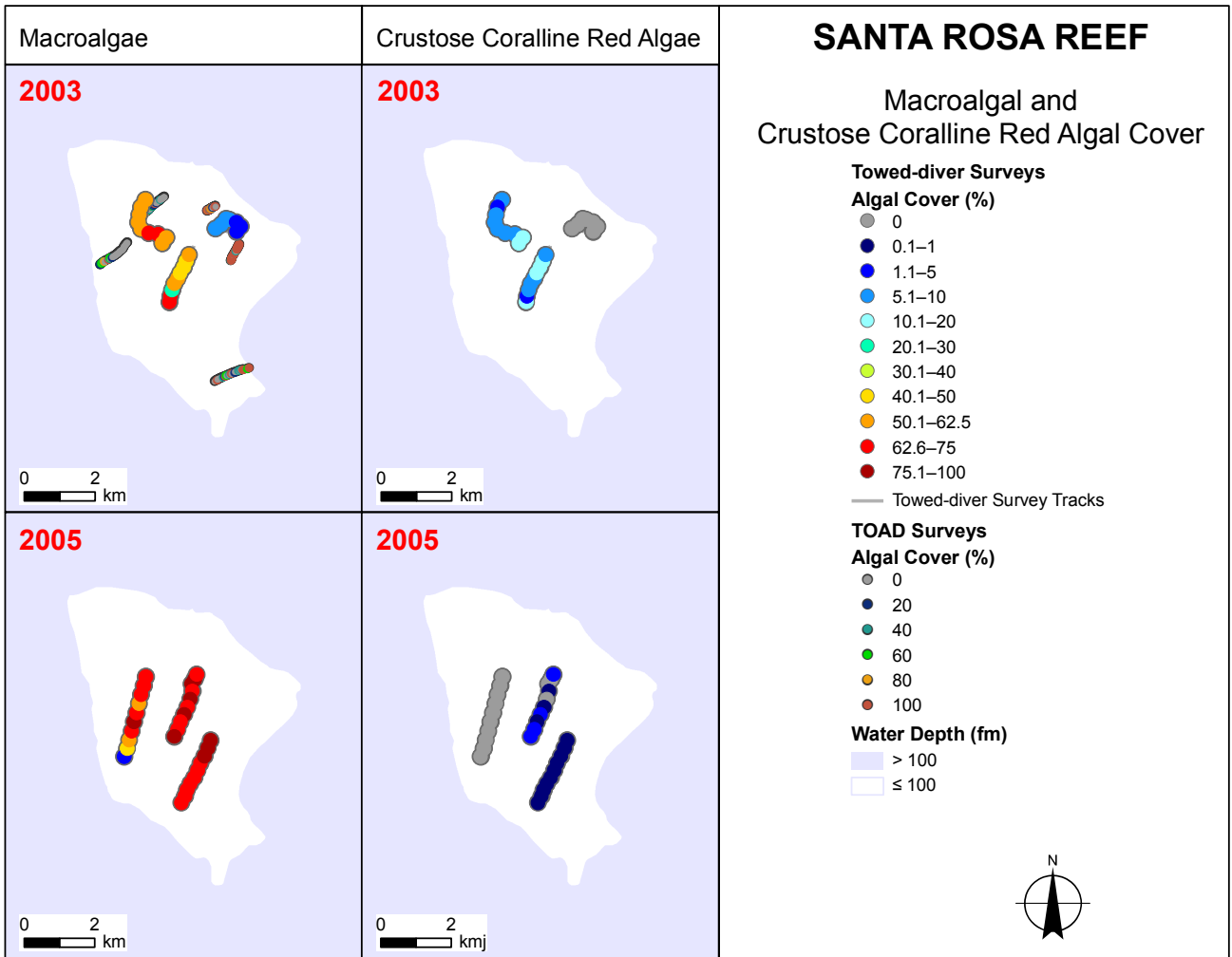
Figure 4.10.6a. Cover (%) observations for macroalgae and crustose coralline red algae from towed-diver and TOAD benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Each large, colored point represents an integrated estimate over a 5-min observation segment covering a survey swath of ~ 200 × 10 m (~ 2000 m²). In both 2003 panels, each small, colored point represents an estimate of algal cover from TOAD surveys. The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003).

During MARAMP 2005, 2 REA benthic surveys were conducted using the line-point-intercept method on Santa Rosa Reef. Site-specific estimates of macroalgal cover on this reef in 2005 were 60.8% at SRR-02 and 44.1% at SRR-01 (Fig. 4.10.6b). No crustose coralline red algae were observed at SRR-02, and cover of crustose coralline red algae at SRR-1 was 4.9%. Finally, turf-algal cover was 8.8% at SRR-02 and 9.8% at SRR-01.

2005

SANTA ROSA REEF
Algal Cover

Algal Cover (%)

36 — Number corresponds to total cover (%) of algal functional groups at each site.

Pie-chart size is proportional to total algal cover.

Water Depth (fm)
- > 100
- ≤ 100

SRR-02 70

SRR-01 59

Functional Groups
- Crustose Coralline Red Algae
- Macrolalgae
- Turf Algae

N

0   2
km
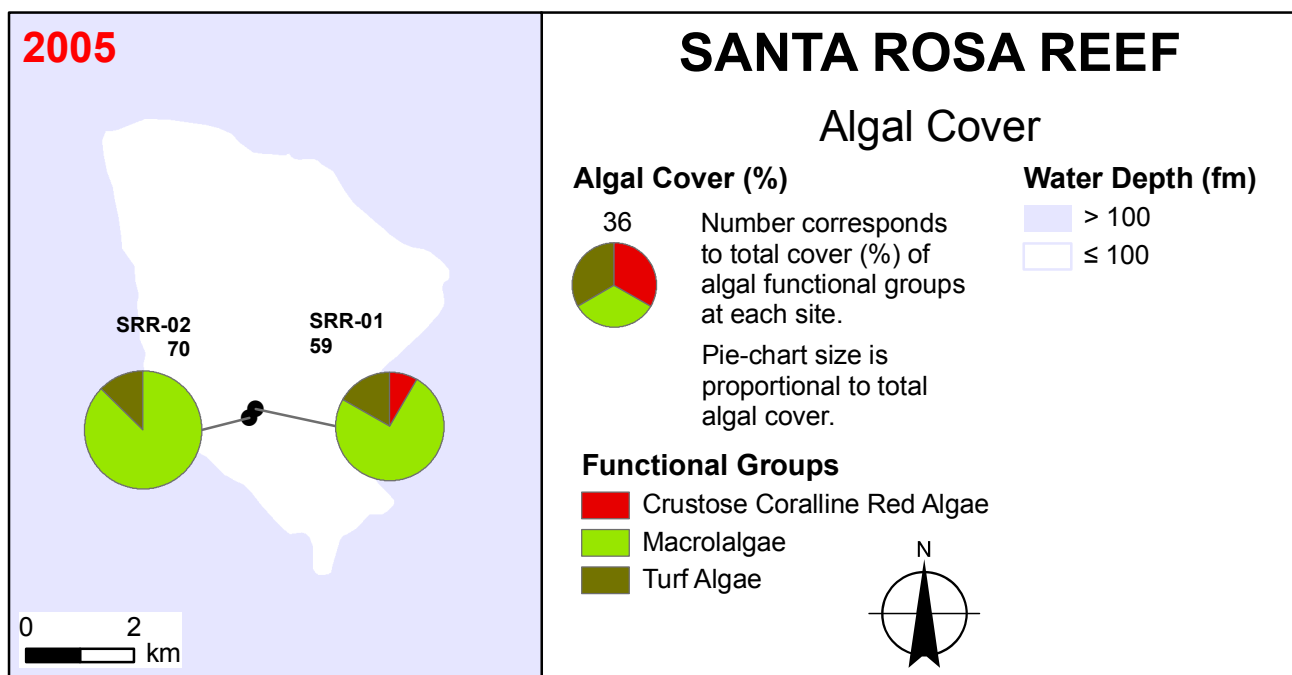
Figure 4.10.6b. Observations of algal cover (%) from REA benthic surveys conducted using the line-point-intercept method on Santa Rosa Reef during MARAMP 2005. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.

Between MARAMP survey years, overall mean macroalgal cover for Santa Rosa Reef increased from 42% in 2003 to 71% in 2005 (Fig. 4.10.6c). Meanwhile, overall mean cover values for crustose coralline red algae at this reef declined by 93% from 7% in 2003 to 0.5% in 2005. These results were from towed-diver surveys completed at a nearly identical time of year, in late September 2003 and early October 2005, and, thus, a seasonal shift in algal composition does not explain this algal cover variation between survey years. Also, turf algae were included in surveys of macroalgal cover in 2003 but not in 2005 (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

Macroalgae
- Towed Diver 2003
- Towed Diver 2005 and 2007
- REA

Crustose Coralline Red Algae
- Towed Diver
- REA
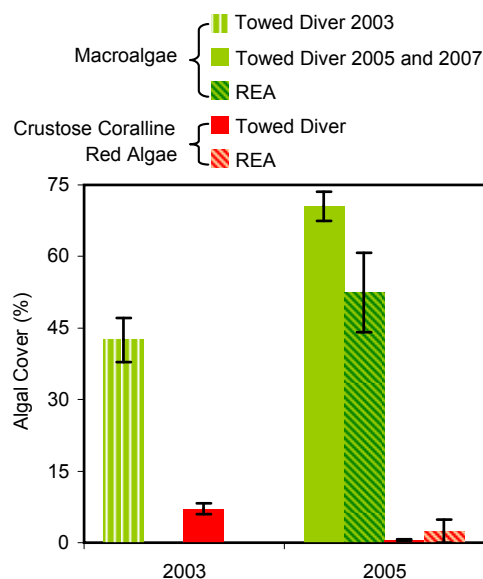
Figure 4.10.6c. Temporal comparison of algal-cover (%) values from surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted on Santa Rosa Reef in 2003. Error bars indicate standard error (± 1 SE) of the mean.

Macroalgal Genera and Functional Groups

When considering these results, keep in mind that the tentative generic names reported in this section from field surveys may change and algal diversity for each site will increase once laboratory-based taxonomic identification of all algal species is completed (see Chapter 2: "Methods and Operational Background," Section 2.4.6: "Algae and Algal Disease").

During MARAMP 2003, REA benthic surveys were conducted at 1 site on Santa Rosa Reef. Eight macroalgal genera (1 red, 6 green, and 1 brown), containing at least 9 species and 1 additional algal functional group, turf algae, were observed in the field.

The most widely distributed algal genera at the single site surveyed on Santa Rosa Reef in 2003 were the chlorophytes *Halimeda* and *Microdictyon*, occurring in 100% of sampled photoquadrats (Fig. 4.10.6d, left panel). Species of the algal genus *Dictyosphaeria* were also common, occurring in 75% of sampled photoquadrats. The genus *Udotea* was observed in 58.3% of the photoquadrats sampled at SRR-02. Species of the genera *Avrainvillea* and *Caulerpa* and the brown algal genus *Lobophora* were equally frequent, each occurring in 16.7% of sampled photoquadrats. Members of the red algal order Gelidiales occurred in 91.7% of sampled photoquadrats.

Turf algae were exceptionally common, occurring in 100% of sampled photoquadrats (Fig. 4.10.6d, left panel). In addition to macroalgae, turf algae made up the only other functional group recorded at the 1 site surveyed in 2003.

During MARAMP 2005, REA benthic surveys were conducted at 2 sites on Santa Rosa Reef. Thirteen macroalgal genera (2 red, 10 green, and 1 brown), containing at least 17 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, branched nongeniculate calcified red algae, and cyanophytes—were observed in the field. Macroalgal generic diversity was approximately equal at both sites with 10 genera observed at each site.

The most widely distributed algal genera at the sites surveyed on Santa Rosa Reef in 2005 included species of the green algal genera *Halimeda* and *Dictyosphaeria*, which occurred in 91.7% and 79.2% of sampled photoquadrats (Fig. 4.10.6d, right panel). Species of the algal genera *Avrainvillea*, *Caulerpa*, and *Microdictyon* were also common, occurring in 62.5%, 62.5%, and 66.7% of sampled photoquadrats. The genus *Udotea* was observed in 58.3% of sampled photoquadrats. *Chondrophycus*, *Liagora*, and *Lobophora* were the only red or brown algal genera recorded at these sites. Although spatial trends are difficult to determine based on the small number of surveys conducted, it was noted that species of both *Chondrophycus* and *Liagora* only occurred at SRR-02, while species of *Neomeris* only occurred at SRR-01.

Turf algae and cyanobacteria were both common, occurring in 87.5% and 58.3% of photoquadrats sampled on this reef (Fig. 4.10.6d, right panel). Turf-algal communities, ubiquitous at both sites, were found in 75%–100% of sampled photoquadrats. At both sites, cyanobacteria were observed in 41.7%–75% of sampled photoquadrats, and branched non-geniculate coralline red algae were a prominent component of the algal community at SRR-01, occurring in 50% of sampled photoquadrats.
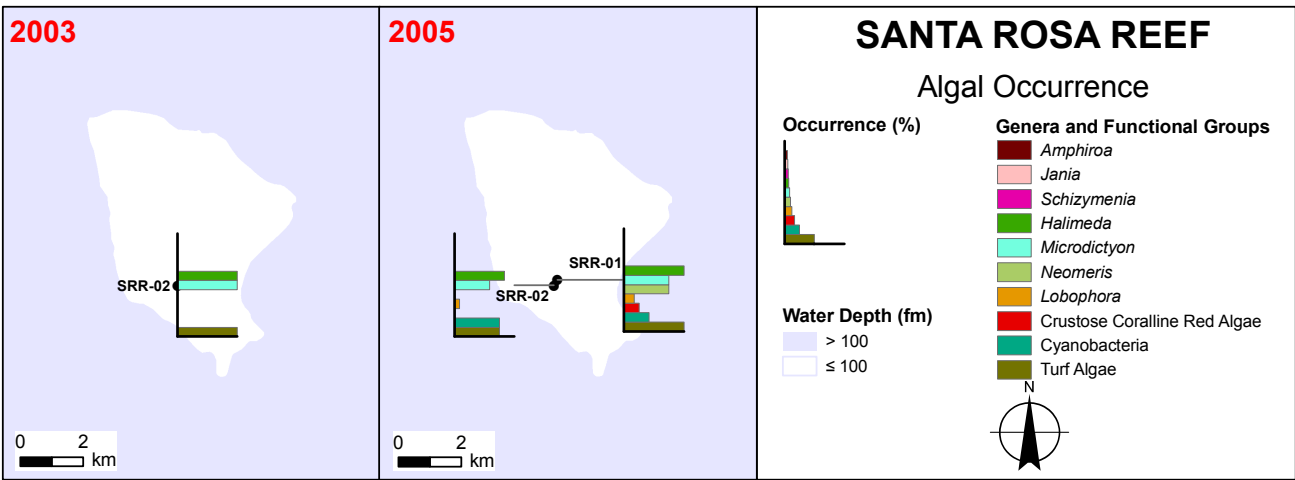

Figure 4.10.6d. Observations of occurrence (%) of select macroalgal genera and algal functional groups from REA benthic surveys on Santa Rosa Reef during MARAMP 2003 and 2005. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

The overall occurrence of macroalgal genera on Santa Rosa Reef did not fluctuate greatly between MARAMP 2003 and 2005. Species of the genera *Halimeda* and *Microdictyon*, during both survey years, consistently were observed at the highest mean occurrence values of 91.7%–100% and 66.7%–100% (Fig. 4.10.6e). The occurrence of the genus *Caulerpa* was low in 2003, when it was only recorded in 16.7% of the photoquadrats sampled at SRR-02; however, its occurrence increased drastically to 58.3% in 2005 at the same site. The occurrence of the genus *Liagora* was low in 2003, when it was not recorded in the photoquadrats sampled at SRR-02; however, its occurrence increased to 25% in 2005 at the same site. The occurrence of members of the order Gelidiales was high in 2003, when they were recorded in 91.7% of sampled photoquadrats; however, their occurrence decreased drastically to 0% in 2005. Green algae were dominant at SRR-02 during the 2 survey years and at SRR-01 during the 1 year it was surveyed—and members of the order Gelidiales and the genera *Chondrophycus*, *Liagora*, and *Lobophora* were the only brown or red algal taxa recorded at these sites.

During MARAMP 2003 and 2005, turf algae occurred in 100% and 87.5% of photoquadrats sampled on Santa Rosa Reef (Fig. 4.10.6e). Crustose coralline red algae occurred in 0%–12.5% of sampled photoquadrats across survey years, while cyanobacteria occurred in 0%–58.3% of sampled photoquadrats, and branched, nongeniculate, calcified red algae occurred in only 0%–25% of sampled photoquadrats. These patterns of increasing occurrence may result from the increased survey effort in 2005, and additional observations are necessary for confirmation.

The number of macroalgal genera recorded on Santa Rosa Reef increased from 9 to 13 between MARAMP 2003 and 2005. Such an increase in generic diversity is not enough to suggest environmental or benthic compositional change, since seasonal variability can greatly affect algal abundance. Additionally, other factors could contribute to minor differences in observed biodiversity (see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").
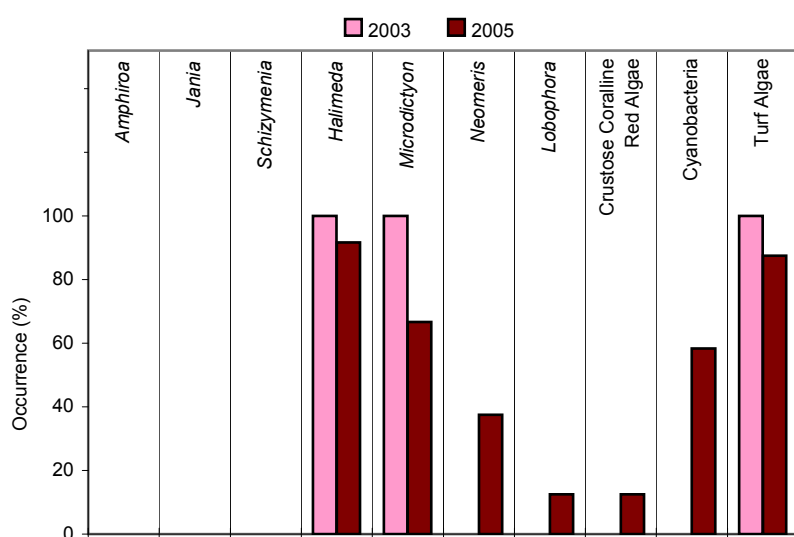
igure 4.10.6e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups on Santa Rosa Reef during MARAMP 2003 and 2005.

4.10.7 Macroinvertebrate Surveys

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at 1 of the 2 REA sites surveyed and in all 3 of the towed-diver surveys conducted on Santa Rosa Reef (Fig. 4.10.7a, left panel; Fig. 4.10.7b). The density of giant clams at SRR-02 was 1 organism 100 m^{-2}. The overall mean density of giant clams from towed-diver surveys was 0.023 organisms 100 m^{-2} (SE 0.006). The highest mean density of giant clams from a towed-diver survey was 0.027 organisms 100 m^{-2} with segment densities ranging from 0 to 0.099 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed in all 3 of the towed-diver surveys conducted on Santa Rosa Reef (Fig. 4.10.7a, right panel) with an overall mean density of giant clams of 0.028 organisms 100 m^{-2} (SE 0.007). The highest mean density of giant clams from a towed-diver survey was 0.036 organisms 100 m^{-2} with segment densities ranging from 0 to 0.162 organisms 100 m^{-2}.
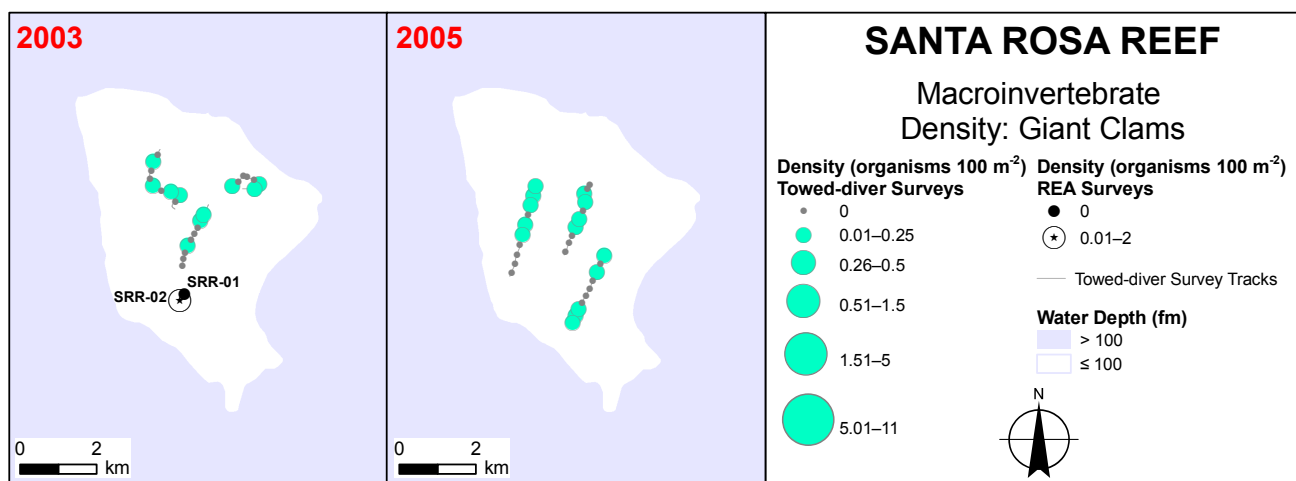
Figure 4.10.7a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005.
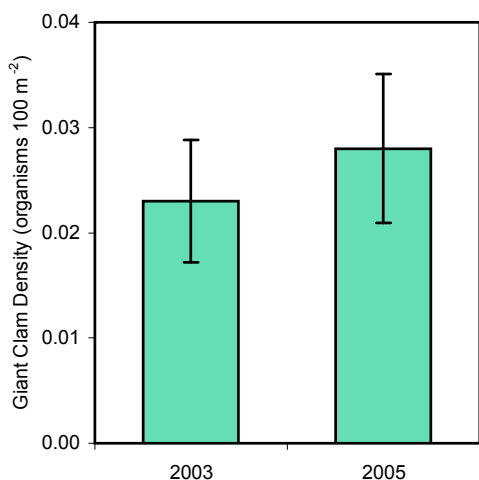
Figure 4.10.7b. Temporal comparison of mean densities (organisms m^{-2}) of giant clams from towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Crown-of-thorns Seastars

During MARAMP 2003 and 2005, no crown-of-thorns seastars were found during towed-diver surveys on Santa Rosa Reef.

Sea Cucumbers

During MARAMP 2003, sea cucumbers were observed in all 3 of the towed-diver surveys conducted but were not seen at either of the 2 REA sites surveyed on Santa Rosa Reef (Fig. 4.10.7c, left panel; Fig. 4.10.7d). The overall mean density of sea cucumbers from towed-diver surveys was 0.068 organisms 100 m^{-2} (SE 0.013). The highest mean density of sea cucumbers from a towed-diver survey was 0.139 organisms 100 m^{-2} with segment densities ranging from 0.047 to 0.246 organisms 100 m^{-2}.

During MARAMP 2005, sea cucumbers were observed in all 3 of the towed-diver surveys conducted on Santa Rosa Reef (Fig. 4.10.7c, right panel) with an overall mean density of 0.047 organisms 100 m^{-2} (SE 0.010). The highest mean density of sea cucumbers from a towed-diver survey was 0.09 organisms 100 m^{-2} with segment densities ranging from 0 to 0.179 organisms 100 m^{-2}.

Figure 4.10.7c. Densities (organisms 100 m⁻²) of sea cucumbers from REA and towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003.

Figure 4.10.7d. Temporal comparison of mean densities (organisms m⁻²) of sea cucumbers from towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.
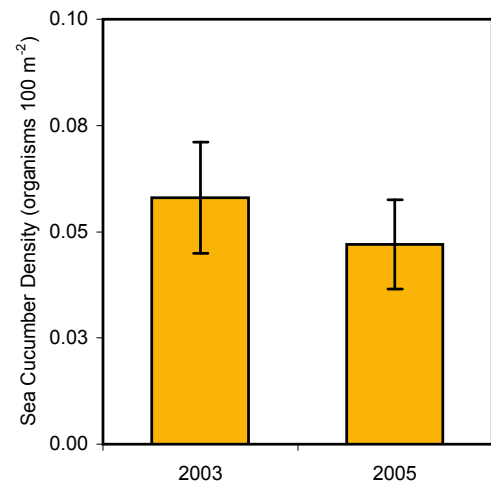
Sea Urchins

During MARAMP 2003, sea urchins were observed at 1 of the 2 REA sites surveyed and in all 3 of the towed-diver surveys conducted on Santa Rosa Reef (Fig. 4.10.7e, left panel; Fig. 4.10.7f). The density of sea urchins at SRR-02 was 25 organisms 100 m⁻². The overall mean density of sea urchins from towed-diver surveys was 5.28 organisms 100 m⁻² (SE 0.957). The highest mean density of sea urchins from a towed-diver survey was 10.7 organisms 100 m⁻² with segment densities ranging from 8.97 to 12.55 organisms 100 m⁻². Three species were observed on Santa Rosa Reef: blue-black urchin (*Echinothrix diadema*) and rock-boring urchins *Echinometra mathei* and *Echinostrephus aciculatus*. The rock-boring urchin *E. aciculatus* accounted for 60% of sea-urchin density in 2003.

During MARAMP 2005, sea urchins were observed in all 3 of the towed-diver surveys conducted on Santa Rosa Reef (Fig. 4.10.7e, right panel) with an overall mean density of 1.63 organisms 100 m⁻² (SE 0.240). The highest mean density of sea urchins from a towed-diver survey was 2.83 organisms 100 m⁻² with segment densities ranging from 1.61 to 5.26 organisms 100 m⁻².

Figure 4.10.7e. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005.
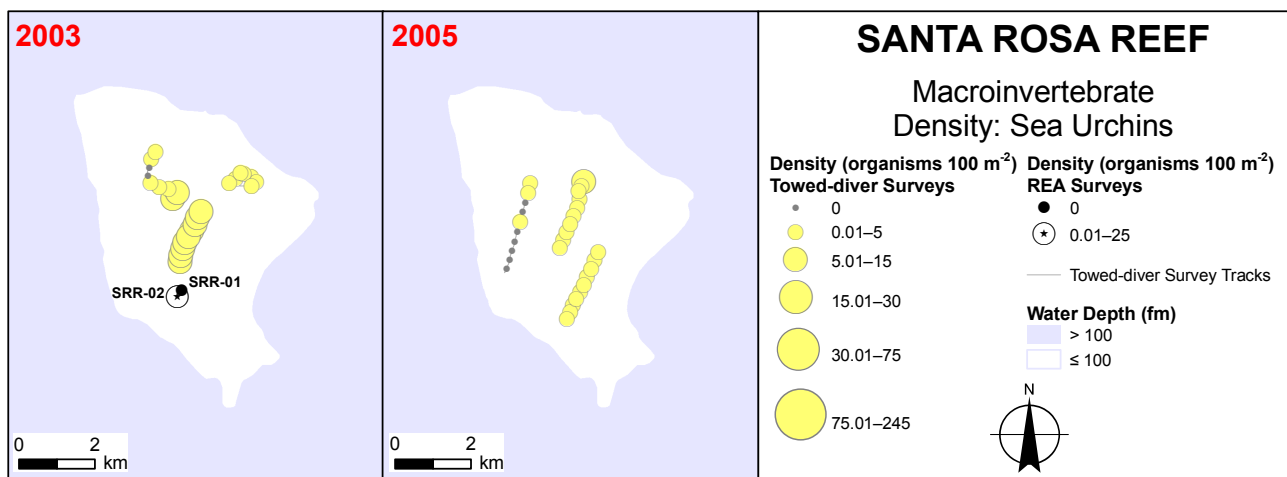

Figure 4.10.7f. Temporal comparison of mean densities (organisms m^{-2}) of sea urchins from towed-diver benthic surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.
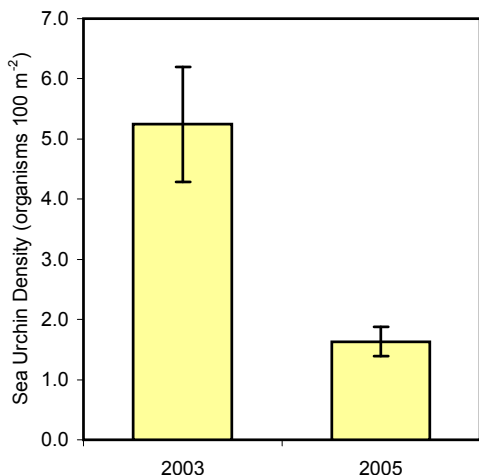
4.10.8 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 3 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted on Santa Rosa Reef (Fig. 4.10.8a, left panel), revealing an overall mean of 0.16 kg 100 m^{-2} (SE 0.1) for the biomass of large fishes on this reef (biomass values were calculated as weight per unit area). A single eagle ray (*Aetobatus narinari*) accounted for more than half of overall large-fish biomass: 54% or 0.09 kg 100 m^{-2}. Parrotfishes (Scaridae) accounted for the second-greatest proportion of large-fish biomass: 28% or 0.05 kg 100 m^{-2}. The steephead parrotfish (*Chorurus microrhinos*) was the most abundant parrotfish among large-fish species, accounting for 83% of parrotfish biomass. Surgeonfishes (Acanthuridae) were also common during this survey period, and the bulbnose unicornfish (*Naso tonganus*) was the most common species, contributing 0.02 kg 100 m^{-2} to large-fish biomass. No sharks were observed at Santa Rosa Reef in 2003.

During MARAMP 2005, 3 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted on Santa Rosa Reef (Fig. 4.10.8a, right panel), revealing an overall mean of 0.22 kg 100 m^{-2} (SE 0.16) for the biomass large fishes on this reef. A single porcupine ray (*Urogymnus africanus*), accounted for the highest proportion of overall large-fish biomass: 82% or 0.18 kg 100 m^{-2}. Grunts (Haemulidae) accounted for the second-greatest proportion (15%) of large-fish biomass, and the painted sweetlips (*Plectorhinchus picus*) was the most abundant grunt, contributing 0.03 kg 100 m^{-2} to large-fish biomass. Snappers (Lutjanidae) accounted for the remainder (3%) of large-fish biomass but were not commonly observed. The twinspot snapper (*Lutjanus bohar*) was the only snapper species recorded during this survey period. As with MARAMP 2003 observations, no sharks were observed at Santa Rosa Reef in 2005.
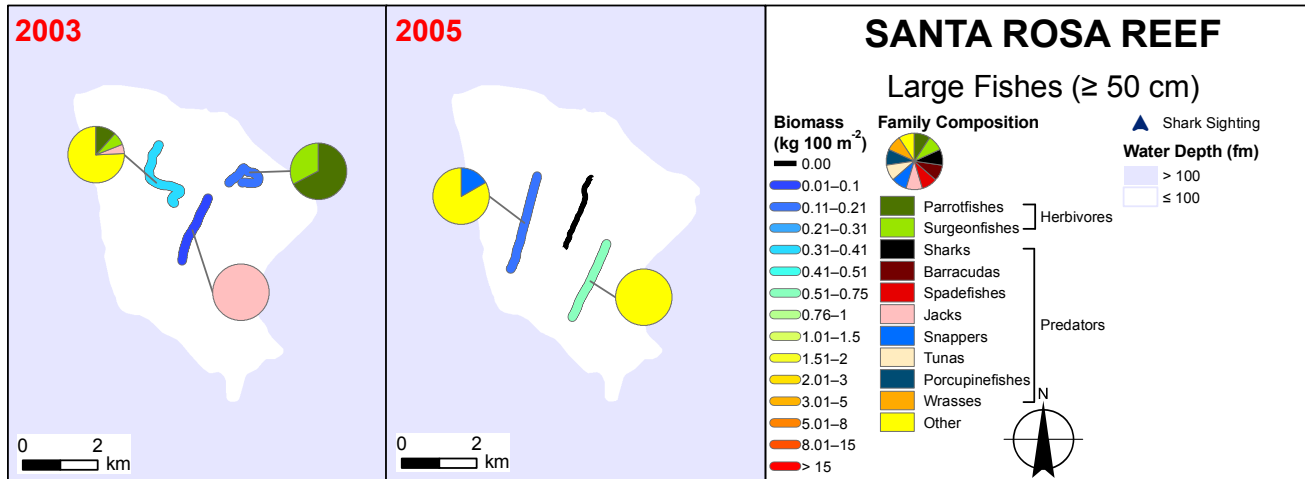
Figure 4.10.8a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) and family composition on Santa Rosa Reef during MARAMP 2003 and 2005. No sharks were observed.

Overall, estimates of large-fish biomass from towed-diver surveys conducted on Santa Rosa Reef were moderately low during MARAMP 2003 and 2005, compared to observations made at other survey areas in the Mariana Archipelago, with means of 0.15 (SE 0.10) and 0.21 kg 100 m^{-2} (SE 0.16, Fig. 4.10.8b). During both survey years, no single species consistently accounted for the greatest proportion of large-fish biomass from towed-diver surveys, and no clear spatial patterns were seen in the distribution of large-fish biomass. Of note was the lack of sightings of large, predatory species like reef sharks (Carcharhinidae) during either survey period. Additionally, no humphead wrasse (*Cheilinus undulatus*) were observed.

Figure 4.10.8b. Temporal comparison of mean values of large-fish biomass (kg 100 m^{-2}) from towed-diver fish surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.
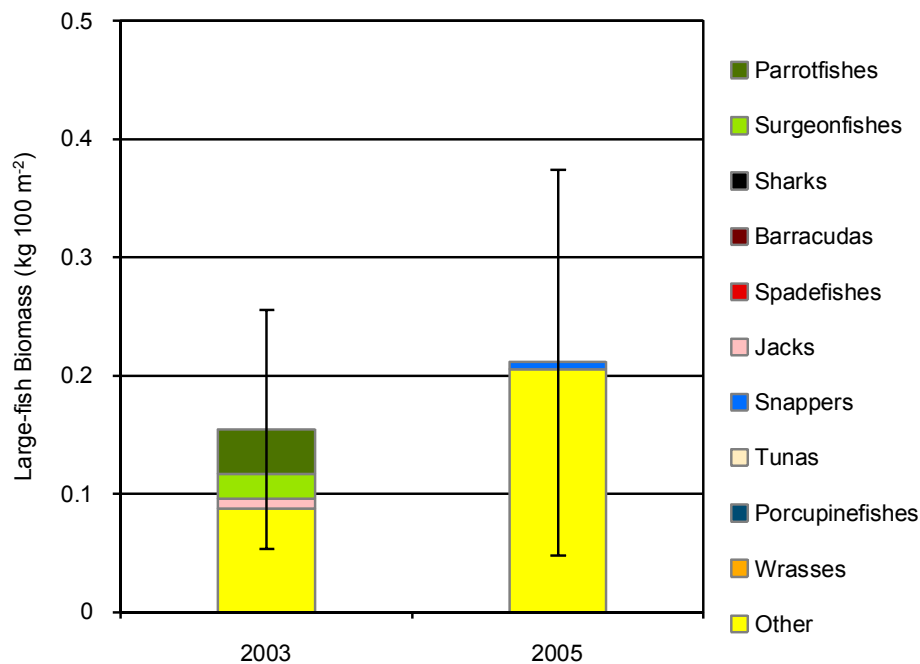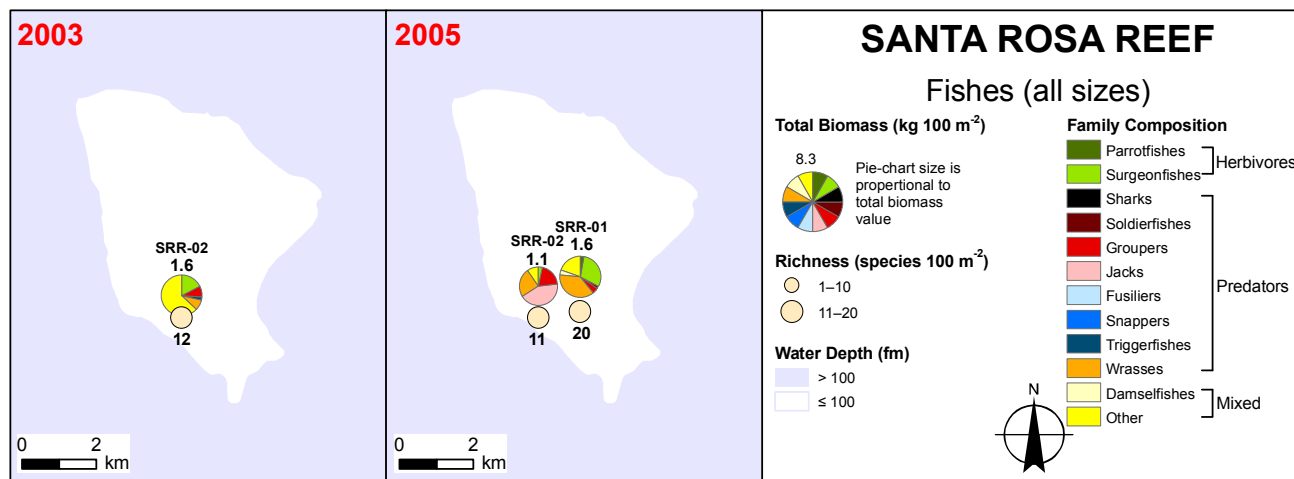
Total Fish Biomass and Species Richness

Total fish biomass from the single REA site surveyed on Santa Rosa Reef during MARAMP 2003 was 1.61 kg 100 m^{-2} (Fig. 4.10.8c, left panel), very low compared to other sites in the Mariana Archipelago. Emperors (Lethrinidae) accounted for the greatest proportion of total fish biomass: 54% or 0.87 kg 100 m^{-2}, and the spotcheek emperor (*Lethrinus rubrioperculatus*) was the only emperor species recorded. Surgeonfishes accounted for the second-greatest proportion of total fish biomass: 17% or 0.28 kg 100 m^{-2}. The orangespot surgeonfish (*Acanthurus olivaceus*) accounted for 97% of surgeonfish biomass. No large, predatory species, such as reef sharks, were observed in 2003.

Based on the single REA survey conducted during MARAMP 2003, species richness was low on this reef compared to other survey sites in the Mariana Archipelago with 12 species 100 m^{-2} (Fig. 4.10.8c, left panel) and a total of 21 species observed. Wrasses (Labridae) were the most represented family with 7 species observed. The pink-belly wrasse (*Halichoeres margaritaceus*) was the most abundant species overall with 15 individuals 100 m^{-2}. The manybar goatfish (*Parupeneus multifasciatus*) was also abundant with 13 individuals 100 m^{-2}.

Total fish biomass for the 2 REA sites surveyed on Santa Rosa Reef during MARAMP 2005 was very low compared to other sites surveyed in the Mariana Archipelago. The highest total fish biomass of 1.63 kg 100 m^{-2} was observed at SRR-01 in the central region of this reef (Fig. 4.10.8c, right panel). Wrasses accounted for the greatest proportion (32%) of total fish biomass. Katherine's wrasse (*Cirrhilabrus katherinae*) and the pink-belly wrasse were the 2 major wrasses by biomass, contributing 0.12 kg 100 m^{-2} and 0.11 kg 100 m^{-2} to total fish biomass. Surgeonfishes and jacks (Carangidae) accounted for the second- and third-greatest proportions (19% and 17%) of total fish biomass. The brown surgeonfish (*Acathurus nigrofuscus*) was the major surgeonfish species by biomass and accounted 76% or 0.20 kg 100 m^{-2} of surgeonfish biomass. The island trevally (*Carangoides orthogrammus*) was the only jack species observed on this reef. No reef sharks were observed in 2005.

Based on REA surveys conducted during MARAMP 2005, diversity was heterogeneous between sites on Santa Rosa Reef with 20 and 30 species observed at SRR-02 and SRR-01 (Fig. 4.10.8c, right panel). Species richness was 20 species 100 m^{-2} at SRR-01 and 11 species 100 m^{-2} at SRR-02. Wrasses and damselfishes (Pomacentridae) were the 2 most represented families, each with 6 species observed in 2005. Katherine's wrasse was the most abundant species overall with more than 40 individuals 100 m^{-2}.

Figure 4.10.8c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method on Santa Rosa Reef during MARAMP 2003 and 2005.

Compared to the rest of the Mariana Archipelago, total fish biomass from REA surveys conducted on this reef was low (Fig. 4.10.8d) with a sample mean over both MARAMP 2003 and 2005 of 1.49 kg 100 m^{-2} (SE 0.13). No spatial patterns in total fish biomass could be identified because of the limited number of sites surveyed. Surgeonfishes accounted for the second-greatest proportion of total fish biomass in both survey years, with the orangespot surgeonfish and brown surgeonfish as the 2 main surgeonfish species by biomass in 2003 and 2005. Large, predatory species, such as reef sharks, were not observed during either survey period.

The total number of species observed during MARAMP 2003 and 2005 ranged from 20 to 30 species with mean species richness of 14 species 100 m^{-2} (SE 1.6) over both survey periods. Wrasses were consistently the most represented family with an average of 6.5 species observed over the 2 survey periods. No single species was the most abundant for both survey periods. However, Katherine's wrasse and the pink-belly wrasse were some of the most abundant species in 2003 and 2005.
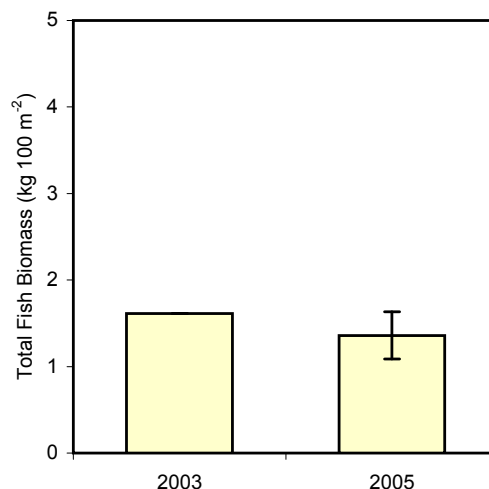
Figure 4.10.8d Temporal comparison of mean values of total fish biomass (kg 100 m^{-2}) from REA fish surveys conducted on Santa Rosa Reef during MARAMP 2003 and 2005. The error bar indicates standard error (± 1 SE) of the mean.

4.11   Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Guam are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. Biological information from towed-diver surveys was integrated to derive 3 composite indices that provide assessments of the relative ecological conditions of forereef habitats in the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan.

The *Benthic Condition Index* for Guam, Rota, Tinian, and Saipan was derived by equally weighting observations of the following 5 parameters from towed-diver benthic surveys around these 4 islands: cover of live hard corals, stressed corals, macroalgae, and crustose coralline red algae and density of crown-of-thorns seastars (COTS). The *Fish Condition Index* for Guam, Rota, Tinian, and Saipan was derived from 2 equally weighted parameters from towed-diver fish surveys: density and biomass of large fishes (≥ 50 cm in TL). The overall *Coral Reef Condition Index* for Guam, Rota, Tinian, and Saipan was derived from an equal weighting of these benthic and fish indices. These condition indices were calculated using ranks assigned to the biological variables from towed-diver surveys conducted around Guam, relative to all surveys performed around the 4 populated, southern islands for each survey year. To indicate changes in these ranks between survey years, these indices were visualized on a map within survey areas, which are represented by color-coded and irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007 (towed-diver-survey tracks were often similar but not exactly the same in each survey year). For more details about the methodology *behind these indices, see Chapter 2: "Methods," Section 2.5: "Ecosystem Integration." Each of these 3 condition indices is presented for Guam on a map in Figure 4.11a. Reef condition indices for the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparison," providing ranks for Guam as well as the 13 islands of the CNMI that are also covered in this report.

Surveys around Pati and Ritidian Points

Portions of the Pati Point Marine Preserve around the northeastern corner of Guam stand out as areas with overall reef conditions that are among the best when compared to conditions around the other populated, southern islands in the Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan (Fig. 4.11a). Pati Point Marine Preserve, which is shown in Figure 4.11b, extends along the northeastern perimeter of Andersen Air Force Base. The geomorphology and habitat within this preserve are diverse, with seagrass and both shallow-water and deepwater coral ecosystems. A well-defined channel is found within this preserve (NOAA 2006). Guam Public Law 24-21 established this preserve in 1997 along with 4 other marine preserves around Guam (Burdick et al. 2008), and enforcement within these preserves began in 2001. Hook-and-line fishing from shore is allowed in this preserve for all species. Trolling is allowed only for pelagic fishes, such as tunas (Scombridae) and billfishes (Scomberesocidae), in all the preserves seaward from the reef margin. In addition to its inclusion in an MPA, the area around Pati Point derives further protection from the limited accessibility associated with its proximity to Andersen Air Force Base.
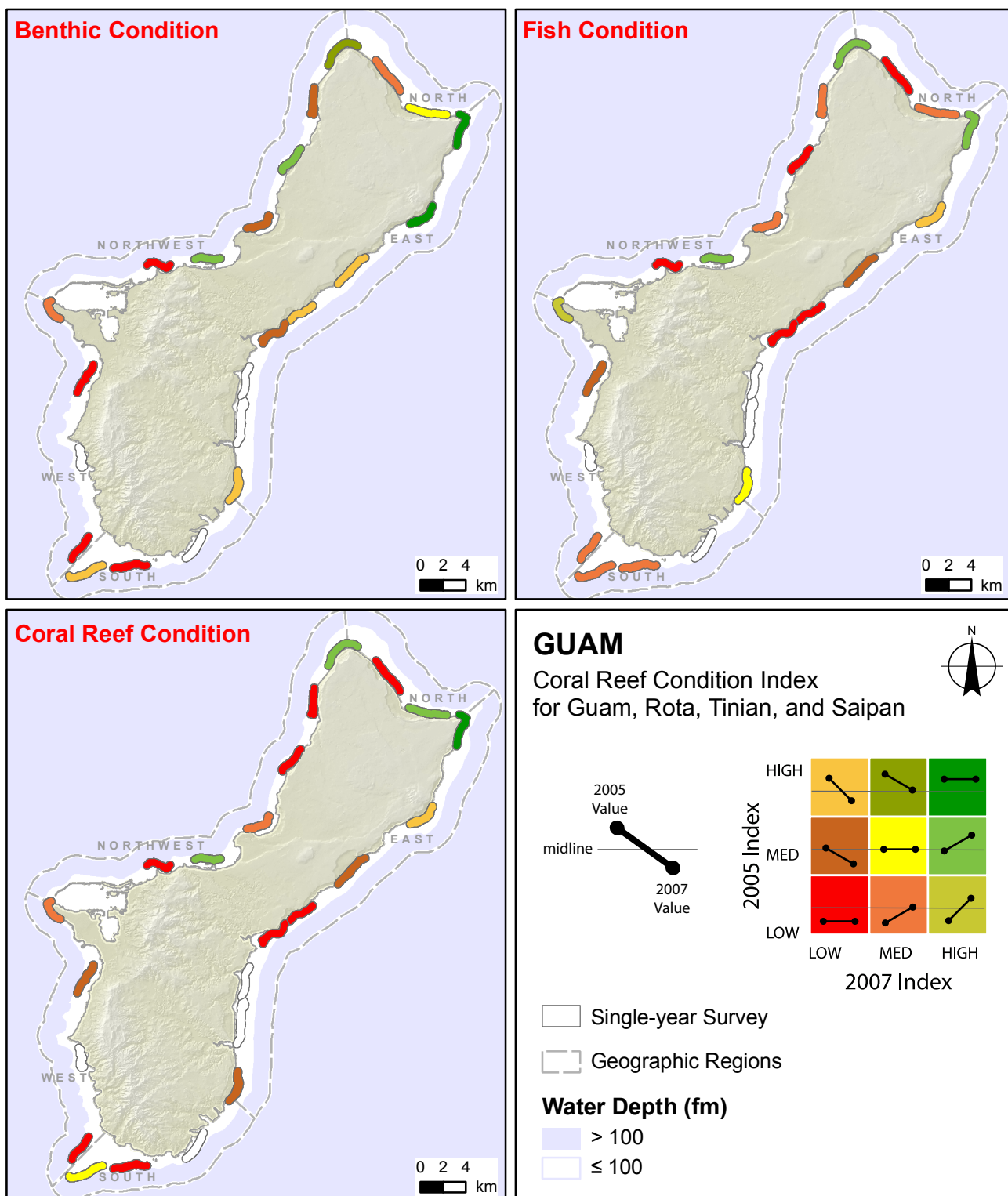
Figure 4.11a. The Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan, as well as the associated Benthic Condition Index and Fish Condition Index, reflects the condition of the benthic and fish communities and their integrated ecosystem for each towed-diver-survey area, *relative to other survey areas around the 4 populated, southern islands.* These maps indicate changes in index ranks between MARAMP 2005 and 2007 for towed-diver-survey areas around Guam. Survey areas are represented by irregular polygonal buffers derived from towed-diver-survey tracks that overlapped in 2005 and 2007. No index value is calculated for areas with only one year of survey data. A high rank means superior condition relative to other survey areas around the 4 populated, southern islands. The survey area around Pati Point, the northeastern point, for example, has a high rank for both 2005 (y-axis) and 2007 (x-axis) and, thus, is assigned the bright-green color that corresponds to the top-right square in the legend. The position of the horizontal bar above the midline in this square also reflects that this survey area maintained a high rank in both years.

The highest biomass of large fishes ($\geq$ 50 cm in TL) of 1.23 kg 100 m^{-2} was found during the MARAMP 2003 towed-diver survey conducted around Pati Point, with 3 reef sharks (Carcharhinidae) recorded in this area (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"). Additionally, the Fish Condition Index for Guam, Rota, Tinian, and Saipan, which uses MARAMP 2005 and 2007 data only, shows that, relative to other areas around the populated, southern islands, the fish community around Pati Point was in good condition. Parrotfishes (Scaridae) and other fish families that are heavily exploited around Guam were commonly observed around Pati Point, and 1 whitetip reef shark (*Triaenodon obesus*) was observed in 2005 at REA site GUA-07. The Fish Condition Index value for the area around and south of Pati Point increased from medium in 2005 to high in 2007, and the rank in this index for the survey area west of Pati Point in the north region increased from low in 2005 to medium in 2007.

Interestingly, these indices suggest that the benthic communities to the west and south of Pati Point were markedly different. Cover values for live hard corals from towed-diver surveys were higher west of Pati Point than south of it, with mean coral cover across the 3 MARAMP survey years of 30% west of Pati Point and 14% south of it. In the Benthic Condition Index for Guam, Rota, Tinian, and Saipan, values for both survey areas were relatively stable. The index rank for the area west of Pati Point was medium in both 2005 and 2007. The index value for the survey area around and south of this point was high in both years (Fig. 4.11a) because, in 2005 and 2007, the ratio of mean cover values for crustose coralline red algae to macroalgae was relatively high, the levels of stressed-coral cover were relatively low, and no COTS were observed. Benthic habitat characterization also reveals differences between these 2 towed-diver-survey areas near Pati Point. South of this point, irregular pavement flats and areas of high rugosity habitat with rocky pillars and boulders were seen. In contrast, the habitat west of Pati Point was more sheltered and consisted of rolling reef. These observed differences in benthic habitats and coral communities south and west of Pati Point were likely a result of mean annual wave forcing; both episodic storm and trade wind waves impact Guam from the east, hindering coral recruitment. A secondary potential reason for these differences was that transient eddies form off the west and south points of Guam (Wolanski et al. 2003b).

Ritidian Point, which is the northernmost tip of Guam and northwest of Pati Point, had moderate values on the Benthic, Fish, and Coral Reef Condition indices (Fig. 4.11a). Still, the coral reefs around Ritidian Point were notable for condition ranks that were high relative to other locations around the populated, southern islands of Guam, Rota, Tinian, and Saipan. This area in 2005, again relative to other locations around these 4 populated islands, had a high value in the Benthic Condition Index because no COTS were observed there and the mean coral cover of 18% was in the upper range of values seen around these populated islands. The Benthic Condition Index value for this area in 2007 declined to medium, given a reduction in the percentage of live coral cover and increases in the levels of stressed-coral cover and COTS density. The Fish Condition Index value around Ritidian Point was also relatively high compared to other locations, with a rating of medium in 2005 based on a slightly above-average density and biomass of large fishes. For this area in 2007, the Fish Condition Index value increased to high. This improvement was caused by an increase in large-fish biomass that in turn was largely a result of observations of several sharks, which were rarely seen elsewhere around the populated, southern islands.

Surveys around Southern and Southeastern Guam

The conditions of the coral reefs in the areas around southern and southeastern Guam, ranging from Cocos Island in the south region up to Fadian Point in the east region, were of particular concern. In these areas, many important watersheds drain into a number of coral-abundant communities. Across the 3 MARAMP survey years, it appeared that these communities were negatively affected by varying degrees of stressed-coral cover and COTS infestation.

The geology of southeastern Guam substantially influences nearshore reef habitats. A volcanic ridge on the west side of Guam drains into moderately sloped areas of forest and farmland before entering the ocean via numerous river outlets along the east and west coasts. The coral reefs around the southern half of Guam are subjected to a number of significant sediment-related stressors, including upland erosion that is exacerbated by high levels of rainfall and large numbers of forest fires (Burdick et al. 2008).

Each of the 3 MARAMP survey periods coincided with or shortly followed periods of moderate-to-heavy precipitation. MARAMP 2003 surveys were conducted in September, the peak of the rainy season; MARAMP 2005 surveys occurred in October, 1 month after the rainy season; and MARAMP 2007 surveys were conducted in May, 1 month after a slight precipitation increase (see Figure 4.4.2e in Section 4.4.2: "Time-series Observations"). The largest watershed on Guam is the Talofofo River, the mouth of which flows into Talofofo Bay, which is centrally located along the southeastern coast near REA site GUA-06 and within the proximity of several towed-diver-survey tracks. Talofofo River drains an estimated area of ~ 72.8 km^2 (Best and Davidson 1981) and is likely a major influence on nearby coral reefs to the south and north of its entry into the ocean.

Several locations along this southeastern coast have impaired or threatened water quality, according to testing conducted by the Guam Environmental Protection Agency (GEPA) in 2006 and 2007 (GEPA 2008). Among the GEPA's top-10 sources of water impairment on Guam are urban runoff and the application of fertilizers and pesticides, both of which potentially occur in some combination among the small communities, farmland, and 2 golf courses (The Country Club of the Pacific and the Onward Talofofo Golf Club) in southeastern Guam. Depending on the combination of nearshore currents driven by trade wind swells and seasonal fluctuations in the North Equatorial Current, introduced nutrient- and contaminant-enriched sediment and water may be carried either north or south before settling into the marine environment. Such sediment may settle on and directly smother benthic organisms, depending on hydrodynamic conditions like waves and currents. Excess nutrients have been shown to alter the relative composition of benthic communities, for example, by promoting algal growth at the expense of corals (Wolanski et. al. 2003a, 2003b). Observations of sedimentation and evidence of coral disease were recorded during MARAMP 2005 towed-diver surveys conducted between Tagachang Point and Jalaihai Point.

Despite the previously described effects, the benthic communities off the southern and southeastern coasts of Guam were notable for supporting moderately high levels of live coral cover—with the exception of 1 towed-diver-survey area in the south region south of Agfayan Bay where habitat was dominated by macroalgae (Fig. 4.11b). All other surveys conducted in the south and southeast regions reported mean live coral cover of > 10%, and during 2 surveys in 2005—1 south of Cocos Island and 1 just north of Talofofo Bay—mean coral cover ranged close to 40%. The survey area off Jalaihai Point, located at the border of the east and south regions, also supported localized, elevated levels of live coral cover across all 3 survey years. REA surveys at GUA-03 in the south region recorded live coral cover of 26% in 2005, and surveys at GUA-11 in Pago Bay and at GUA-03 both recorded mean coral cover of 12% in 2007.

Figure 4.11b. Cover (%) observations of live and stressed corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Guam during MARAMP 2005 and 2007, presented with geology, watersheds, impaired water sites and other factors (WERI 2009; Gingerich 2003; Tracey et al. 1964; Taboroši et al. 2005; GEPA 2008). Values of coral cover and generic richness represent averages from both survey years, where available; otherwise values represent data from the single year surveyed. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years. Colored outlines represent areas where estimates of stressed-coral cover were > 10%, and diagonal lines or dots indicate areas where COTS density was > 0.15 organisms 100 m^{-2}. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.
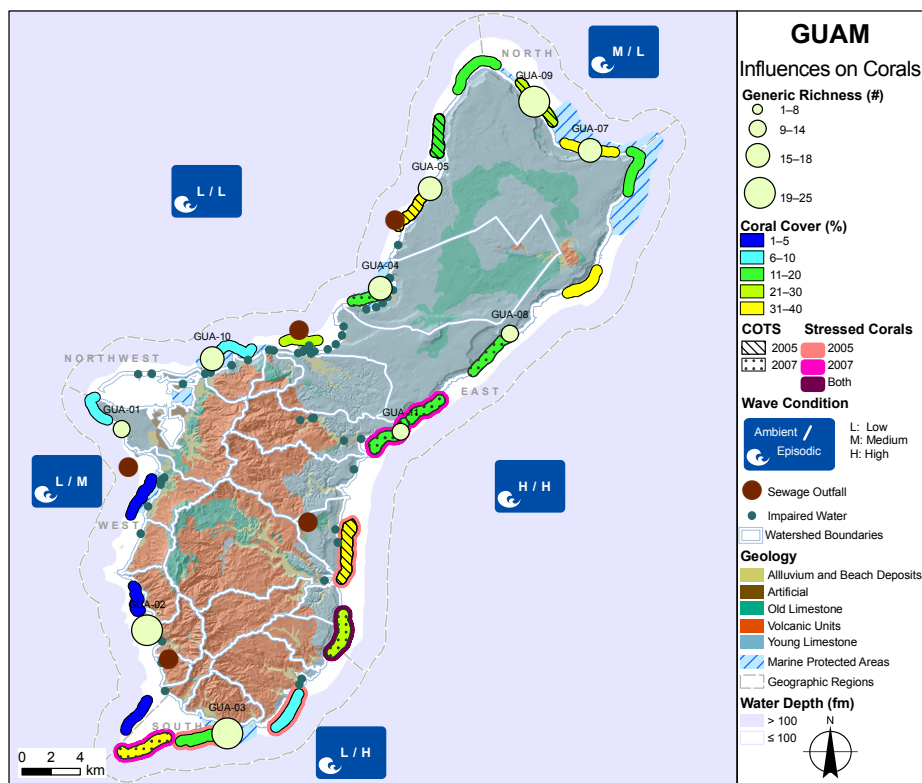
Inconsistent REA and towed-diver-survey efforts around southeastern Guam make comparison across survey years difficult. Still, where towed-diver surveys covered essentially the same area in both 2005 and 2007, it is possible to compare Benthic Condition Index ranks. Declines in Benthic Condition Index values were observed for 1 towed-diver-survey area near Jalaihai Point, located at the border between the east and south regions, and for 2 survey areas south of Cocos Lagoon in the south region (Fig. 4.11a). East of Jalaihai Point, the Benthic Condition Index value was high in 2005 but low in 2007. This drop is attributable to a decline in coral cover, since other benthic parameters remained relatively constant. South of Cocos Lagoon, the Benthic Condition Index values for 2 towed-diver surveys decreased from medium and high in 2005 to low and medium in 2007. Again, declines were mainly because of drops in live coral cover, although, for the most southwestern towed-diver survey, levels of stressed-coral cover and COTS density increased in 2007 from levels in 2005.

One relatively consistent theme for the southeastern coast of Guam was elevated levels of stressed-coral cover. Overall, stressed-coral cover was consistently high in the south and east regions across survey years. COTS predation and bleaching were recorded as the dominant cause of stressed corals. Localized bleaching in Pago Bay in 2004 was reported as a likely result of a large influx of freshwater from Tropical Storm Tingting, and Pago Bay and Achang Reef Flat Marine Preserve were 2 of several areas around Guam where bleaching events, associated with high sea-surface temperatures, were observed in 2006 (Burdick et al. 2008).

COTS were indeed abundant in these regions during MARAMP 2005 and 2007. The highest COTS density for Guam in 2005 was documented during 2 towed-diver surveys conducted north of Talofofo Bay, with certain segments recording densities as large as 4.8 organisms 100 m^{-2}. In 2007, towed-diver surveys recorded 3 of the 4 greatest COTS densities is-landwide around southern and southeastern Guam. The greatest densities occurred off Fadian Point, located north of Pago Bay along the east central coast, with certain segments recording as many as 3.2 organisms 100 m^{-2}. Similarly, Burdick et al. (2008) reported that high densities of COTS were observed in Pago Bay in 2006. The third- and fourth-greatest COTS densities observed around Guam during MARAMP 2007 surveys were recorded off Jalaihai Point and to the south of Cocos Island, where segment densities reached as high as 2.1 and 2.7 organisms 100 m^{-2}, respectively.

Fish biomass around southeastern Guam was consistently low, as it was around most of this island, relative to the rest of the Mariana Archipelago (Fig. 4.11c). Although the human population in southeastern Guam is lower than in other locations around this island, 2 boat launches in the south region provide access to reef resources in this area, and the biomass of large fishes observed around the southeastern coast was not in a higher range than the biomass values recorded around more populated locations.
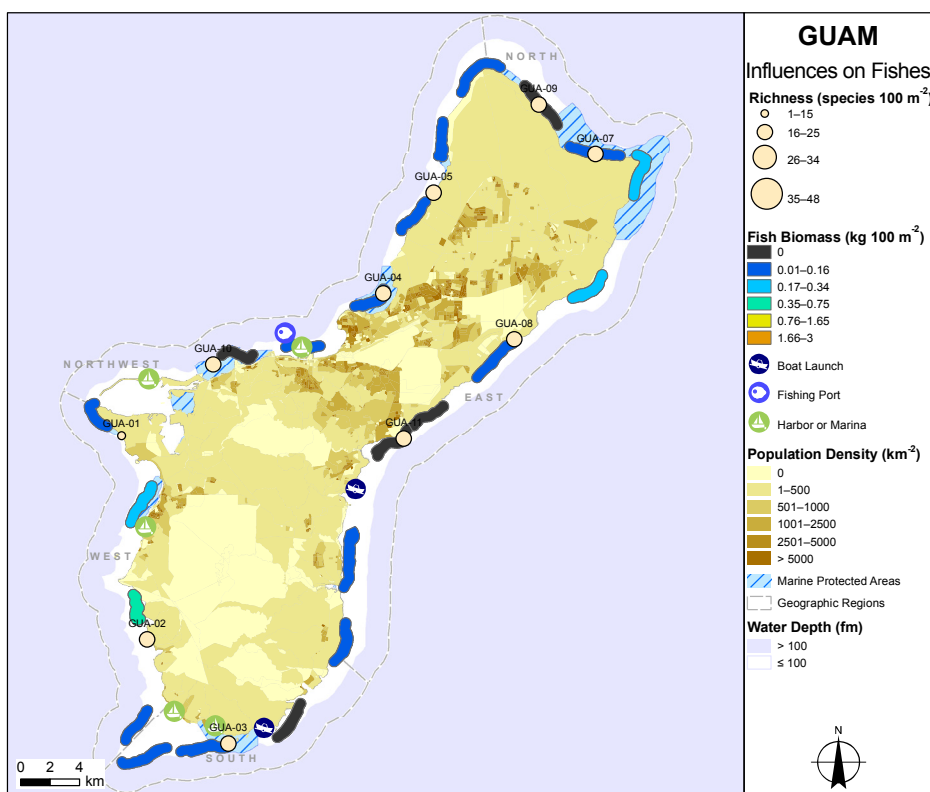
Figure 4.11c. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver surveys and species richness from REA surveys conducted on forer-eef habitats around Guam during MARAMP 2005 and 2007, present-ed over a map of human popula-tion density (U.S. Bureau of the Census 2000, 2008). Biomass and richness values represent averages of data from both survey years, but, if surveys were conducted during one year only, then values represent data from that single year. Towed-diver-survey areas combine overlapping survey tracks for both MARAMP survey years; survey tracks are often similar but not necessarily the same between survey years.

Surveys around Southwestern Guam

In contrast to the east side, the southwestern coast of Guam, in the west geographic region, was notable for supporting some of the lowest levels of live coral cover found around this island (Fig. 4.11b). Mean live coral cover from towed-diver surveys conducted in the west region was 5% in 2003 and 2005 and 3% in 2007, compared to islandwide means of 20% and 23% in 2003 and 2005 and 12% in 2007. Similarly, the lowest coral-cover values in both 2005 and 2007 were recorded at the 2 REA sites in the west region: GUA-02 in Cetti Bay and GUA-01 on the south coast of the Orote Peninsula. Divers described corals at GUA-01 as predominantly small encrusting or nodular varieties and their habitat as low topographic complexity.

The benthic habitats of southwestern Guam were characterized by relatively low live coral cover and high macroalgal cover; together, these 2 ecological parameters resulted in low Benthic Condition Index values for survey areas in the west region (Fig. 4.11a). Among MARAMP 2003 towed-diver surveys, the highest macroalgal cover around Guam was found south of the Orote Peninsula where mean macroalgal cover was 68%. Also in 2003, the highest macroalgal diversity from REA surveys conducted around Guam was recorded at GUA-01. In 2005 and 2007, mean macroalgal-cover values from all 3 towed-diver surveys conducted within the west region were high: more than half of the surveyed area had macroalgal cover of > 75%. The dominant genera observed were the calcareous green alga *Halimeda* and the brown alga *Padina*. Similar results were found at the 2 REA sites surveyed in the west region, revealing algal communities dominated by *Halimeda* and turf algae and relatively low levels of crustose coralline red algae. Extensive mats of turf algae and cyanobacteria were also reported at those sites.

Habitat maps suggest that the pattern of macroalgae-dominated reefs observed in MARAMP survey areas in the west region is typical for the west region as a whole. Created by the NOAA Center for Coastal Monitoring and Assessment by interpreting IKONOS satellite imagery, these maps also show widespread dominance of turf algae in nearshore (< 40 m) reef communities (NOAA 2005).

The nature of the reef community along the southwest coast of Guam is likely a result of both natural and anthropogenic factors. Influences on the habitat type in this area include onshore and nearshore geology and topography, which is characterized by steeply sloping volcanic rock forming ridges and valleys. This geologic setting differs from other parts of Guam, such as the northern area, where an onshore limestone plateau is mirrored in the adjacent coastal waters by a series of flat, carbonate terraces. These terraces provide large areas of shallow, hard substrate that are conducive to reef development.

As discussed earlier in this section, the volcanic landscape of southwestern Guam is characterized by many streams that drain the upland watersheds, transporting terrigenous sediments into nearby coastal waters. Sediment loading and associated freshwater input result in reduced reef development in the coastal areas immediately adjacent to river mouths (Burdick et al. 2008). These factors also influence the composition of the benthic substrate with sandy channels forming in the coastal waters downstream of river mouths, which are shown on the hard-soft and hill-shaded bathymetric maps (Fig. 4.11d). Divers described the habitat in this area as sloping pavement, dropping off to sand, and they noted the presence of sand channels.
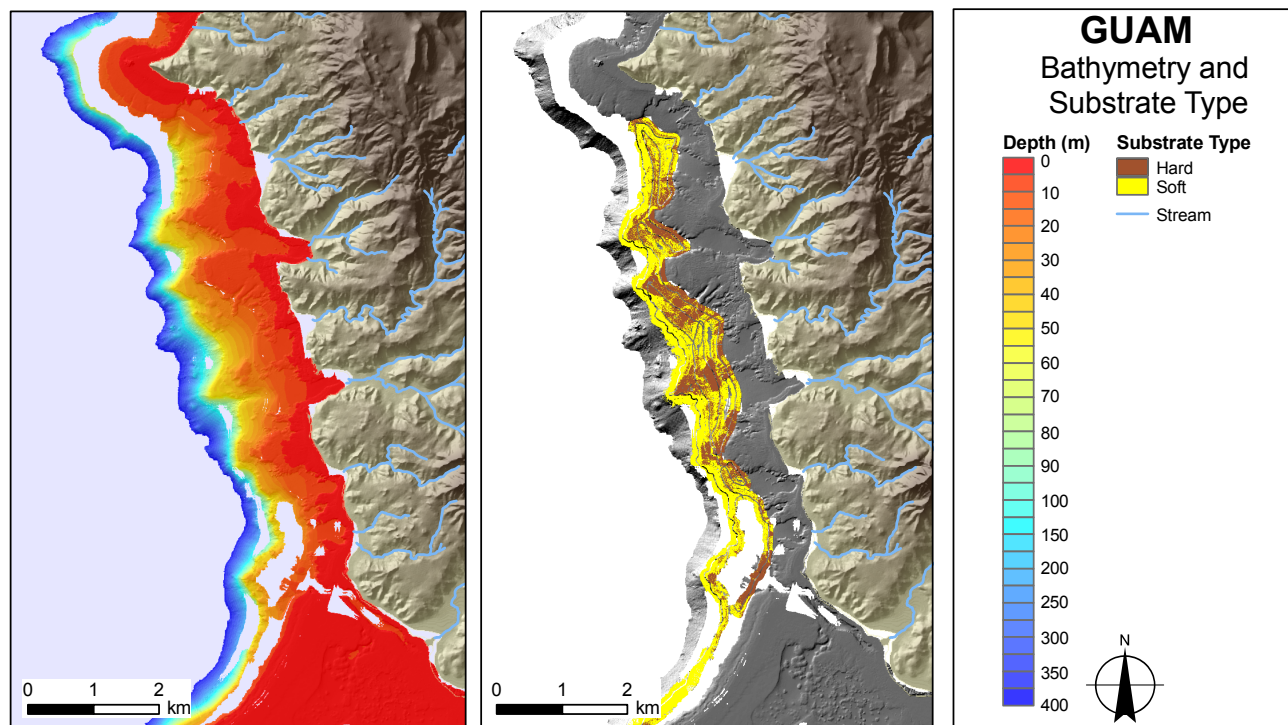
Figure 4.11d. The southwestern coast of Guam, showing (*left*) river channels and associated channels in multibeam bathymetry and (*right*) distribution of soft sediment in relation to river mouths and submarine channels.

In addition to a lack of favorable substrate for reef development and elevated terrigenous sediment input, another factor potentially influencing reef communities around southwestern Guam is the poor water quality of portions of the coastline in this area. Close to Agat Bay, the Agat-Santa Rita Wastewater Treatment Plant has had many documented failures to meet standards of discharge limitations for biological oxygen demand, suspended solids, bacteria, and metals. Incidences of impaired water quality have also been observed farther south close to Cetti Bay (Burdick et al. 2008; GEPA 2008).

Despite low coral cover, coral diversity at GUA-02 in Cetti Bay was relatively high with at least 20 coral genera observed at this site in 2007, compared to the range of 15–23 genera found at REA sites around Guam. In addition to relatively high levels of generic richness, values of stressed-coral cover from towed-diver surveys were relatively low in this area with < 10% for both MARAMP 2005 and 2007. Similarly, in 2007, REA coral-disease surveys recorded prevalence values of only 0.8% and 0.6% at sites GUA-01 and GUA-02, compared to an island maximum of 3.9%; these low levels of coral disease are not surprising given the low levels of coral cover. The main causes of stressed corals were bleaching, predation, and fungal infection.

The reef-fish community surveyed at GUA-01 and GUA-02, the 2 REA sites located in the west region on the southwestern coast of Guam, had some of the lowest biomass and species richness recorded at any of the sites around Guam. The biomass of large fishes from towed-diver surveys was low in this region relative to the rest of Guam (Fig. 4.11c). These results may be in part a consequence of the low structural complexity of the habitat together with limited coral cover and associated shelter habitat that are important to many reef-fish species.

Surveys in Tumon Bay

A final area of interest is Tumon Bay in the northwest region. The entire bay is encompassed by the Tumon Bay Marine Preserve, a broad crescent-shaped limestone platform. Tumon Bay is 3.2 km in length and this reef platform is as wide as 440 m. A major road parallels the beach around this bay ~ 300 m from the high-water mark, making Tumon Bay an important center for recreational activity (NOAA 2006).

Tumon Bay is the focal point of Guam's tourism industry. Most of the hotels and shopping malls on Guam are located in this area, and development along this bay has been rapid in the recent past (Burdick et al. 2008). This area also has the highest human population density on Guam. This area is subject to a variety of anthropogenic impacts, including impaired water quality, sedimentation (siltation stress, re-suspension, etc.), contaminated groundwater, and physical damage to reefs associated with high levels of recreation (Burdick et al. 2008). Further, relatively high densities of COTS were observed during towed-diver surveys conducted along the forereef habitats within Tumon Bay in both 2003 and 2007 (Fig. 4.11e).
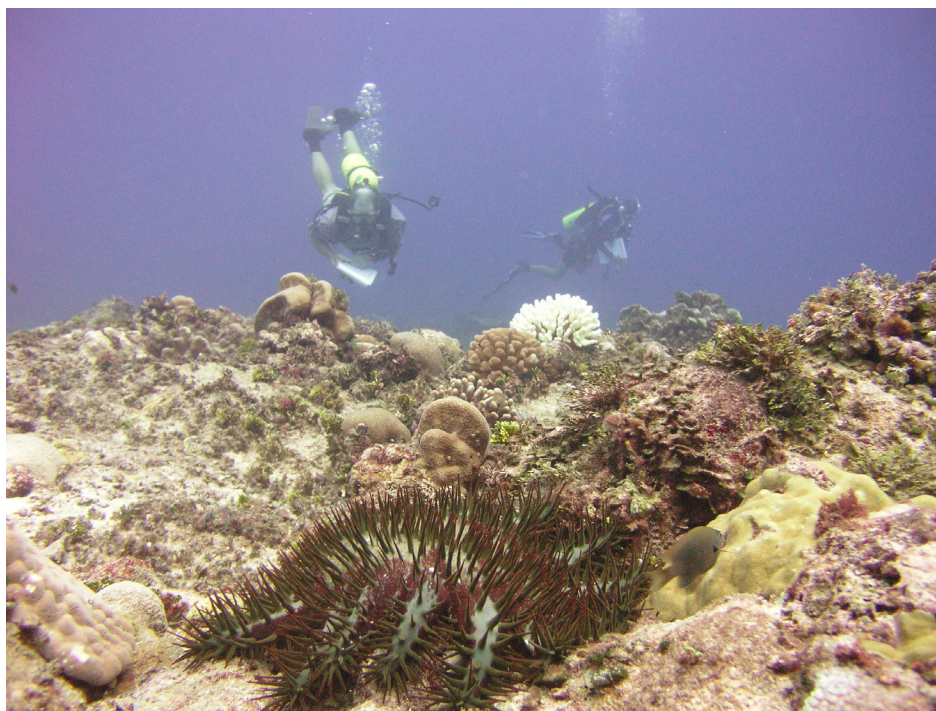
Figure 4.11e. A crown-of-thorns seastar (*Acanthaster planci*) preys on corals in Tumon Bay. NOAA photo by Robert Schroeder

Despite the large human population near and frequent use of Tumon Bay and the numerous associated impacts, the Benthic Condition Index value for this area was medium in both 2005 and 2007 (Fig. 4.11a). This stability may reflect that many potential impacts have been occurring for some time and the ecosystem in this area may have been damaged prior to the first MARAMP survey period in September 2003. Also, many potential land-based impacts likely take place on the shallow reef flat of the backreef that was not covered by MARAMP surveys. Relatively low values of stressed-coral cover were recorded in Tumon Bay during towed-diver surveys, with stressed corals observed during only a few survey segments in 2007. In 2006 and 2007, coral bleaching was documented within the Tumon Bay Marine Preserve, and Brown (2007) reported that more than 60% of the corals there were affected by bleaching and suffered either partial or full mortality. However, MARAMP towed-diver surveys conducted in 2007 associated observations of stressed-coral cover with COTS predation, and bleaching was not recorded. This difference may result from the fact the coral bleaching reported by Brown was documented at depths < 7 m, shallower than the habitat usually covered by MARAMP towed-diver surveys.

Within the Tumon Bay Marine Preserve, regulations prohibit various fishing activities. Fishing from shore by hook and line or cast net, per Guam Public Law 24-21, is allowed for rabbitfishes (Siganidae), juvenile goatfishes (Mullidae), juvenile jacks (Carangidae), and convict tangs (Acanthuridae). Use of cast nets along the reef margin is also allowed for rabbitfishes and convict tangs. Regulations prohibit "bottom fishing" in this preserve at depths < 30.5 m. Trolling for pelagic fishes, including all billfishes and any other migratory oceangoing fishes, is allowed in all the marine preserves around Guam from the reef margin seaward. Despite this remaining degree of fisheries protection in this preserve, towed-diver surveys of the forereefs of Tumon Bay recorded very low biomass of large ($\geq$ 50 cm in TL) fishes in all years, generally with only a few individuals per survey. Across the 3 MARAMP survey years combined, mean total fish biomass at GUA-04 was 3.8 kg 100 m^{-2}, slightly higher than the overall mean of 3.2 kg 100 m^{-2} (SE 0.8) for Guam, which was the lowest value of mean total fish biomass for any island surveyed in the Mariana Archipelago.

4.12   Summary

This section presents an overview of the status of coral reef ecosystems around the island of Guam and some of its adjacent banks as well as some of the key natural processes and anthropogenic activities influencing these ecosystems. MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Guam. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this Guam chapter are included in the appropriate discipline sections. One noteworthy limitation, for example, is the focus of MARAMP observations on forereef habitats to the exclusion of the many shallow backreef flats around Guam. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter.

To simplify interpretation of ecosystem conditions around Guam, a Benthic Condition Index, a Fish Condition Index, and an integrated Coral Reef Condition Index were developed to reflect ecosystem conditions at specific locations around Guam, relative to locations around the 4 populated, southern islands of Guam, Rota, Tinian, and Saipan and based on MARAMP 2005 and 2007 surveys only (see Section 4.11: "Ecosystem Integration"). By synthesizing large amounts of complex, interdisciplinary information, these reef condition indices assist resource managers in identifying potential relationships between various ecosystem components. The condition of the fish and benthic communities and of the overall ecosystem around Guam, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: "Archipelagic Comparisons."

The following summary highlights key attributes of the coral reef ecosystems around Guam and its surrounding reefs and banks (for place-names and their locations, see Figure 4.2a in Section 4.2: "Survey Effort"):

- Guam is by far the largest island in the Mariana Achipelago and supports 70%–75% of this archipelago's human population. The bulk of Guam's population is centered on the northern part of this island.

- Divided by the Pago-Adelup fault, the northern and southern halves of Guam have distinct geologic characteristics. Uplifted, volcanic rock is capped by limestone in the northern half, creating a flat setting with little surface water. Volcanic rock in the southern half results in a steep, rugged landscape drained by numerous streams and rivers.

- The benthic seascape north and south of the Pago-Adelup fault reflects Guam's onshore landscape. Around northern Guam, a series of low-rugosity carbonate platforms with shallow terraces are separated by relatively steep slopes

from deeper waters. These relatively deep areas have steep ridges and debris resulting from mass-wasting. In contrast, around southern Guam, fewer platforms are present, and they are narrow. There are some areas of steep-sided canyons, for example, along the south and southwest coasts. Overall, the southern half of Guam has a more topographically complex seabed with fewer flat areas in comparison to the seabed around northern Guam.

- One of the major economic drivers on Guam is tourism. Tourism is concentrated in the Tumon Bay area, which has the highest population density on this island. This area is subject to a variety of anthropogenic impacts, including impaired water quality, sedimentation, contaminated groundwater, and physical damage to reefs associated with high levels of recreation. In the Benthic Condition Index for Guam, Rota, Tinian, and Saipan, the rank for this area was similar (medium) for both MARAMP 2005 and 2007. That this area is an MPA, established in 1997, suggests how an area so heavily populated and stressed by tourism and overfishing may have been able to maintain a medium condition for benthic populations. Total fish biomass, calculated as weight per unit area, however, was low in Tumon Bay during both survey years.

- A major factor in Guam's economic future is the expansion of U.S. military facilities on Guam, given plans to move ~ 25,000 military personnel and family members, including at least 4700 Marines from Japan, to Guam in the next decade. This influx of people would represent an increase of ~ 25% in this island's population. Major construction projects would include expansion of commercial piers, construction of docking facilities for an aircraft carrier, and construction of housing and facilities. Along with development related to tourism, this added population and con-struction load is expected to have significant environmental impacts, both on land and to the coral reef ecosystems of Guam.

- Wave model output shows typical trade wind swells from the north and east as well as high wave energy from storm tracks from the southeast. Vertical gradients in all oceanographic parameters measured were consistently stronger in the areas sheltered from easterly trade winds than in other areas around Guam.

- STR and satellite-derived (Pathfinder) SST data show that temperatures surpassed the bleaching threshold for a brief period in September 2006.

- Turbidity was very low with beam transmission > 90% at most CTD cast locations at Guam; however, lower beam transmissions was observed in Apra Harbor.

- Islandwide estimates of live-hard-coral cover from towed-diver surveys revealed variation between survey years, with mean values of 19% in 2003 and 23% in 2005 decreasing to 12% in 2007. A comparable pattern was discernible from estimates based on site-specific data from REA surveys: overall mean coral cover around Guam decreased from 26.1% in 2005 to 16.2% in 2007, with declines seen at all of the 7 sites surveyed in both 2005 and 2007. Despite this temporal trend, mean coral cover for Guam was intermediate (~ 10%–20%) relative to values observed around other islands in the Mariana Archipelago.

- The highest level of coral disease was documented in the north region near Jinapsan Point; however, observations of disease prevalence in this area were still relatively low with ~ 3%. Coral disease was assessed only during MARAMP 2007, and all REA sites surveyed contained disease. Bleaching was the most common affliction encountered, with 39% of cases, and was widely distributed around Guam.

- Fish biomass, from both REA and towed-diver surveys, was lowest around Guam compared to the rest of the Mariana Archipelago in all years surveyed. No clear geographic trend in overall fish biomass was observed across years. Large-fish-biomass values from towed-diver surveys conducted around Guam were generally highest in the most remote areas of Guam, including near Pati Point, the northeastern tip of this island, where large surgeonfishes (Acanthuridae), parrotfishes (Scaridae), and reef sharks (Charcharhinidae) were observed.

- Ranks from the Coral Reef Condition Index for Guam, Rota, Tinian, and Saipan and the Benthic Condition Index for the survey area around Ritidian Point, where the Guam National Wildlife Refuge is located, were high in 2005, but values from both indices for this area declined to medium by 2007 (a high rank reflects superior condition relative to other survey areas around the 4 populated, southern islands). These drops in both indices represent a potential cause for concern, and close review of future monitoring information for this area is recommended. Ritidian Point is one of the few places where sharks were sighted in all 3 survey years.

- The condition of the reef in the Pati Point Marine Preserve was among the best observed around the 4 populated, southern islands. The highest numbers of large fishes (≥ 50 cm in TL) were observed in this area in 2007. Ranks from both the Benthic Condition Index and Coral Reef Condition Index were high in both 2005 and 2007.

- In the central area of the east region, from Pago Bay to Campanaya Point, the coral reef ecosystem appeared to be in relatively poor health—with low ranks in all 3 condition indices (Benthic, Fish, and Coral Reef) in 2007. Known, long-term issues of water quality in Pago Bay may affect reef health. Stressed-coral cover and high densities of crown-of-thorns seastars (*Acanthaster planci*) were observed in 2006 (see Section 4.11: "Ecosystem Integration") and in 2007. Also, in 2004 localized bleaching occurred in Pago Bay as a result of a large freshwater input from Tropical Storm Tingting, and high sea-surface temperatures were associated with bleaching on reefs in several areas around Guam, including Pago Bay, in 2006.

- Some of the highest levels of live coral cover were observed near Catalina Point during towed-diver surveys conducted around Guam. Data from towed-diver surveys conducted over all 3 years revealed absence of stressed-coral cover and low densities of crown-of-thorns seastars (COTS) in this area. Macroalgal cover here was moderate to low in comparison to other areas around Guam. These results are reflected in the Benthic Condition Index rank of high for this area in both 2005 and 2007. A possible factor behind these "good" conditions may be this area's distance from Guam's main population centers and their associated anthropogenic impacts. This area is adjacent to Anao Conservation Reserve and just south of Pati Point Marine Preserve.

- The areas along the southern and southeastern shores of Guam, from Cocos Island in the south region up to Faidan Point in the east region, were of particular concern for this island. Many watersheds are located in these areas, so the amount of runoff that flows into the ocean certainly influences nearby coral reef ecosystems. At several locations (see Fig. 4.11b in Section 4.11: "Ecosystem Integration") along this coastline, the Guam Environmental Protection Agency has identified impaired or threatened waters. Despite these pressures, moderately high levels of coral cover were observed off the southern and southeastern shores of Guam. In 2005, COTS predation was greatest between Togcha and Talofofo Bays, where towed-diver surveys documented more than 100 individual COTS during a 5-min segment just south of Togcha Bay. During MARAMP 2003, no COTS were recorded in this area. In 2007, the highest level of stressed-coral cover was observed from Agfayan Bay to Pagat Point, and 91 individual COTS were recorded there, suggesting COTS predation was a factor in this area's elevated levels of stressed-coral cover. Total fish biomass from REA surveys conducted in this area was consistently low.

- The southwestern coast of Guam supported the lowest levels of live coral cover found around this island. These algal-dominated reefs had the highest macroalgal cover found south of Orote Peninsula. Similar to hydrology of the southeastern shore, many streams drain upland watersheds, transporting terrigenous sediments into the adjacent coastal waters. Despite low coral-cover values in Cetti Bay, coral diversity was relatively high around southwestern Guam. Values of stressed-coral cover and coral-disease prevalence were low in this area. Some of the lowest levels of total fish biomass and species richness around Guam were observed here.

- Estimates of live coral cover around Santa Rosa Reef, from towed-diver surveys, revealed stability between survey years, with mean values of 7% in 2003 and 8% in 2005. Elevated coral-cover values were consistently recorded towards the central coasts, rather than perimeter areas, of Santa Rosa Reef.

Errata

Erratum 1—Correction in Chapter 3: "Archipelagic Comparisons," Section 3.1: "Geopolitical Context," P. 1, Table 3.1a:

The brown tree snake symbol was changed from black to grey in the "Animal Threats" column of the rows for Saipan, Tinian, and Rota. A legend for the new grey symbol was added, stating "Brown tree snake sighted but not established." A personal communications was added to the citations in the table caption, "M Onni, CNMI Division of Fish and Wildlife, pers. comm."

Although sightings of the brown tree snake (*Boiga irregularis*) have been reported for Saipan, Tinian, and Rota (Marianas Avifauna Conservation Working Group 2008), efforts by the Brown Tree Snake Program of the Commonwealth of the Northern Mariana Islands (CNMI) Division of Fish and Wildlife (DFW) to keep populations from becoming established outside of Guam have been effective, as the last live snake captured and dead snake found in the CNMI were recorded on Saipan in 2000 and on Rota in 2009, respectively (M Onni, CNMI DFW, pers. comm.)

Erratum 2—Correction in Chapter 4: "Guam & Adjacent Reefs," Section 4.1.4: "Economy," P. 7, lines 1 and 2:

This sentence was redacted: "Two fishing methods have been banned: (1) use of scuba and artificial light for spearfishing and (2) use of monofilament gill nets."

These two fishing methods have not been banned in Guam.

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